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DISEASES OF FIELD CROPS IN ARIZONA

By
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and
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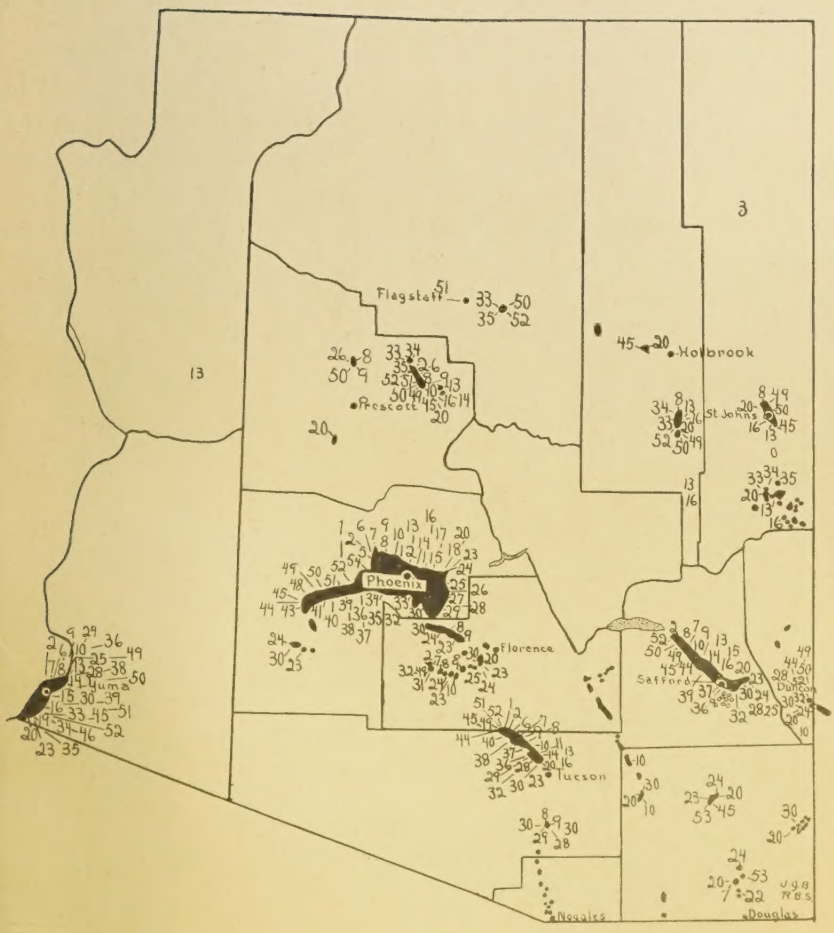

Distribution of diseases of field crops in Arizona (see numbers on pages 86 and 87).

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FOREWORD

The area in Arizona which is devoted to field crops is small when compared with that of less mountainous states, but the production of two or more crops per year makes it more than equal to larger areas in many agricultural states. However, the mildness of climate which permits additional crops is not an unmixed good for it also favors the persistence of certain diseases which are not found in colder regions. On the other hand many diseases of field crops which cause extensive losses elsewhere are absent from Arizona.

Diseases of field crops are important factors in the business of farming; their presence may mean the difference between profit and loss. Unless maximum production per unit of cultivated area is realized the overhead, especially on irrigated land with its extra expenses, is so increased that little or no profit can result. The control of diseases is therefore important; often control can be accomplished at a very low cost.

In writing this bulletin the authors have attempted to use material which has accumulated during their comparatively long experience with plant diseases in Arizona; they have also made use of available pertinent publications. Most diseases herein described occur within the State. However, some diseases are included which have not yet appeared here but which should be watched because they are in a neighboring state or because they are important and uncertain in geographic range.

Finally, the authors realize that a publication which will answer all questions on diseases of field crops, even on the well-known diseases in a limited district, is impossible; therefore they invite correspondence with farmers in Arizona on disease problems which may not be anticipated in this bulletin.

J. G. Brown

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I. KEY TO
DISEASES OF FIELD CROPS IN ARIZONA

ALFALFA

Symptoms	Disease	Cause	Control	Page
Leaf: Pale (light brown) spots with darker margin and scattered black dots on surface.	Ascochyta leaf-spot.	*Ascochyta imperfecta*, a fungus.	See Pseudopeziza leaf-spot.	110
Stem: Water-soaked, yellowish green, elongated spots more numerous on lower part, which become brown to black; spots may show clear, thick, somewhat sticky liquid (bacterial ooze). *Leaf:* Similar but roundish, water-soaked, then brown to black spots. *Plant:* Stems or entire plant above ground may become brittle and die. *Field:* Appears lighter green than healthy fields; disease worse in first cutting but may remain active throughout summer.	Bacterial blight; Sackett's disease.	*Phytomonas medicaginis*, a bacterium.	None entirely satisfactory; early cutting may be advisable.	111
Crown: Rotted and discolored light to dark brown, chiefly downward into central part of root; often appears to be split. *Plant:* Dwarfed and weak; no wilting.	Crown rot.	Plants, apparently weakened by unfavorable conditions such as impermeable soil, frost, or by the trampling of stock when soil is wet, are attacked by *Fusarium species.*	Subsoiling; keep livestock from fields immediately after irrigation.	113

ALFALFA

Symptoms	Disease	Cause	Control	Page
Crown: Rounded, irregular galls from size of pea to walnut; mottled when cut across. *Plant:* Weak stems with yellow foliage or brown, dead stems; entire plant may be killed.	Crown wart.	*Urophlyctis alfalfae*, a fungus.	Badly diseased fields should be plowed under; no alfalfa grown in them for at least 3 years.	115
Plant: Wound about and intertwined by a yellowish, thread-like parasite which produces clusters of white flowers; plants smothered and killed.	Dodder disease.	*Cuscuta spp.*, flowering plants.	Use clean seed; mow and burn over infested spot or badly infested field; grow immune crops for 5 or more years.	115
Leaf: Light green or yellowish green spots on upper side; grayish, downy growth of fungus which becomes pale violet on under side.	Downy mildew.	*Peronospora trifoliorum*, a fungus.	Disease disappears in hot, dry weather; in severe cases, follow directions for control of Pseudopeziza leaf-spot.	117
Plant: Purple, red, then yellow leaves at top; dwarfed or killed. *Stem:* May be purple or reddish green from tip down to girdle; sunken band or girdle at bottom of stem or higher up.	Girdle.	*Stictocephala spp.* *Coccus hesperidum*, insects.	No control measures known; see suggestions, page 120.	118
Leaf: Small, brown, circular spots 1/16 inch in diameter, with very small raised disc in center, especially on lower leaves; yellow leaves except green area around spots; ground often littered with brittle leaves. *Stem:* Same kind of spot described for leaf. *Field:* Second or third cutting usually worst attacked, but disease may appear in fall.	Pseudopeziza leaf-spot.	*Pseudopeziza medicaginis*, a fungus.	Early cutting.	120

Symptoms	Disease	Cause	Control	Page
Leaf: Reddish brown to cinnamon colored spots on either or both surfaces, round, giving a rusty powder when rubbed. *Stem:* Same kind of spot; stems sometimes deformed.	Rust.	*Uromyces striatus*, a fungus.	See Pseudopeziza leafspot.	121
Field: Roughly circular spots with few stunted surviving plants inside and dying plants on margin; spots enlarge during season and may reappear the following year; buff colored spore mats on spots. *Plant:* Wilting and death which may be rapid in hot dry weather; turns brown. *Root:* Taproot killed and more or less rotted; bark slips off; after decay of taproot, a lateral root takes its position; sometimes buff to brown fungus threads can be seen on infected root.	Texas root rot.	*Phymatotrichum omnivorum*, a fungus.	See pages 123-125, 160, 161.	123
Field: Roughly circular spots of dead plants surrounded with wilting, dying plants with yellowed leaves; spots resemble Texas root-rot spots. *Plant:* Taproot and laterals may be rotted; *look for violet fungus threads on decaying roots.*	Violet root rot.	*Rhizoctonia crocorum*, a fungus.	When spots are small, disinfect soil; alfalfa should not be grown in badly infected fields; rotate crops, omitting alfalfa and sweet potato.	126
Leaf: White, or nearly white, spots which vary in size, on margin, tip, or between veins.	White spot.	Unknown.	Unknown	127

BARLEY

Symptoms	Disease	Cause	Control	Page
Stem: Spots of summer spores scattered or running together, linear, yellowish brown becoming darker; spots of winter spores black but otherwise like preceding. *Leaf:* Only sheath spotted unless disease is severe.	Black stem rust.	*Puccinia graminis*, a fungus.	See wheat stem rust, pages 201-204	132
Head: Purplish black spore masses covered, or partly covered, with a silver-gray membrane replace the grains and remain until threshing time.	Covered smut.	*Ustilago hordei*, a fungus.	Use clean seed; treat seed in a machine with Ceresan; seed-treating machine can be cheaply made at home (see pages 214-215)	127
Leaf: Spots of summer spores scattered, oblong or linear, naked, 1/50 to 1/25 inch long, cinnamon brown. Later, spots of winter spores, oblong to elliptical, covered with epidermis, 1/125 to 1/25 inch long, dark gray.	Leaf rust.	*Puccinia anomala*, a fungus.	Of little commercial importance; see wheat stem rust, page 201	132
Head: Olive brown spore masses replace spikelet; spores covered at first but soon blow away, leaving only stalk of head; smut appears at flowering time.	Loose smut.	*Ustilago nuda*, a fungus.	Hot-water treatment and seed plot; Ceresan applied with a machine, pages 207-208, 216	131
Leaf: White patches on older leaves become powdery and may show very small, brown to black specks.	Powdery mildew.	*Erysiphe graminis*, a fungus.	Control measures usually unnecessary here; keep fields free from wild grasses and wild barley; sulphur dust is effective.	132

Symptoms	Disease	Cause	Control	Page
Seedling: Parallel stripes ½ inch to length of blade, pale yellowish green turning dark brown and increasing in size; dead tissues brittle, easily split. *Plant:* Same spots on stem; plant dwarfed to half normal size, broken, frayed; spike fails to appear or only partly emerges from boot; when present, spike brownish and awns distorted. Disease fully developed by flowering time when infected parts show dark areas.	Stripe.	*Helminthosporium gramineum*, a fungus.	Rotation of crops; use seed from fields known to be free from stripe; treat seed with Ceresan, 3 ounces per bushel, machine applied, or with Germisan, 0.25% solution for 1 hour.	133
	BROOMCORN			
	Bacterial stripe.			135
	Covered kernel smut.			135
	Loose kernel smut.			135
	CORN			
Stalk: Watersoaked at one of lower nodes, usually at first node above soil; node becomes light to dark brown, sunken and rotted, and stalk bends over to the ground. *Leaf:* Only lower leaves affected; leaf sheath becomes watersoaked, decays, then whole leaf withers and turns brown.	Bacterial stalk rot.	*Phytomonas dissolvens*, a bacterium.	None known	135
Ear: Light weight, easily twisted off; white or colored mold; butt discolored; kernels loose or break near tip when pulled.	Cob rot.	Various fungi, including *Diplodia* and *Gibberella*.	Select choice seed ears; treat seed.	137

CORN

Symptoms	Disease	Cause	Control	Page
Aerial Parts: Pale, glistening swellings on any above-ground part, commonest on ear and tassel; these are smut boils which finally break open and show a mass of black spores.	Common smut.	*Ustilago zeae*, a fungus.	Collect and burn smut boils in small plantings; plant corn not oftener than once in 3-4 years in field infected with smut; cut badly infected corn for ensilage; use resistant strains.	140
Seedling: Toppling over; stem shows brown, shrunken spot near soil line.	Damping-off.	*Rhizoctonia* and other fungi.	Plant later; use more kernels per hill; use less irrigation water; cultivate frequently.	142
Leaf: Small, brown blisters covered at first, then breaking open exposing spores.	Rust.	*Puccinia sorghi*, a fungus.	No practical method; disease causes slight loss.	142
Seedling: Young plant fails to emerge or dies when small; rotting just above seed, or root may rot.	Seedling blight	Various fungi.	Select choice seed ears; treat seed.	137

COTTON

Leaf: Very small, red spots increase in size, become light colored in center with red margin; become irregular with target-like, concentric rings; may finally be covered with sooty layer of spores; similar spots on bolls, bracts, petioles, pedicels. Leaf fall, boll shedding, boll drying.	Alternaria leaf-spot.	*Alternaria, sp.*, a fungus.	No practical method known. Eradication of weeds may help.	144

Symptoms	Disease	Cause	Control	Page
Seedling: Round, water-soaked spots on one or both seed leaves; water-soaked spots and streaks on edges of injuries and on margin of seed leaves; spots may show a light yellow bacterial ooze; they usually run together and turn almost or quite black as they become older and dry. Same spots, but elongated, on stem of seedling, show later.	Angular leaf-spot	*Phytomonas malvacera*, a bacterium.	Delint seed with concentrated sulphuric acid.	144
Stem: Water-soaked, elongated spots which later become reddish to brownish black, sometimes deep black; may girdle stem; stem becomes weakened and easily broken and may "sprawl" on ground.	Black-arm stage.			146
Leaf: Small, angular, water-soaked spots, or water-soaked streaks along larger veins, which turn black; leaf may be shed.				
Bolls: Small, roundish, water-soaked spots which enlarge and become black in central part with water-soaked margin or, with secondary infection, become reddish or rusty colored; diseased sections dry on outside, contract, cause premature opening; lint stained and weakened; infection of boll stem may cause shedding.	Bacterial boll rot stage.			146
Squares: Either roundish or elongated water-soaked spots which dry and turn black.				
Plant: Entire plant may sprawl on ground because infection so weakens the stems that they can not support weight of leaves and bolls.				

COTTON

Symptoms	Disease	Cause	Control	Page
Boll: Soft, pinkish spot on side of green boll, becoming brown in center with pink margin; surface of spot white later, then gray, then sooty black; spot inside boll pink to purplish with red-brown shades; lint, seeds and capsule destroyed; boll dries without opening if all locks are infected; healthy locks open normally.	Aspergillus boll-rot.	*Aspergillus niger*, a fungus.	Control insects which wound boll and make entrance for fungus.	150
Plant: Normal growth suddenly changes to abnormal growth; lower branches horizontal, but upper ones more or less upright; dwarfing of stems and leaves; wood cylinders divided but bark entire; plant sterile or with only a few bolls.	Crazy-top.	Physiological.	Rotation of cotton with alfalfa, deep irrigation with more constant available soil moisture.	152
Boll: Olive-green spot deepens in color and dries with age; spore masses give to surface dark-gray to blue-gray color; inside boll, infected tissues steel gray to pale purple, with seeds pink to yellow.	Rhizopus boll-rot.	*Rhizopus nigricans*, a fungus.	Control insects which wound boll.	150
Plant: Almost normal at first but becoming dwarfed and yellowed. *Root:* Numerous lumps or galls in roots, very small to ½ inch or more in diameter.	Root knot; nematode disease.	*Caconema radicicola*, a roundworm.	Prevent introduction by strict examination of all rooted plants brought to farm; rotate with root-knot resistant crops; dry fallow with complete elimination of weeds, followed with root-knot resistant crops.	152

Symptoms	Disease	Cause	Control	Page
Plant: Dull green with somewhat wilted leaves; leaves may become yellowed or reddish; later plant breaks at soil line and falls over; older plants less affected and quite resistant at and after chopping time. *Root:* Brown to reddish brown discolored spots at and below the soil line.	Soreshin.	*Rhizoctonia solani*, a fungus.	Plant after soil warms; few but deep irrigations followed by light cultivation.	155
Green Parts: Roughly circular spots 3 16 to $\frac{1}{2}$ inch in diameter on leaves and other green parts; spots dark reddish-purple above, orange yellow below; disease may cause leaf-fall.	Southwestern rust.	*Puccinia hibisciata (Aecidium gossypii)*, a fungus.	No practical method for control.	157
Plant: Wilting during day with recovery at night is followed by permanent wilting and death. *Root System:* Extensively decayed; slender strands, fuzzy, tan to light brown on roots; bark slips off. *Soil:* Spore mats, white at first then tan, may appear on surface. *Field:* Roundish spots of dead, brown plants.	Texas root rot.	*Phymatotrichum omnivorum*, a fungus.	Eradicate first small spots by disinfecting soil; keep larger spots from spreading by using barriers; long rotations with root-rot resistant crops and dry fallow.	159
Plant: May appear stunted; wilts more or less suddenly, especially in midday; finally dies. *Stem:* Central wood seen to be browned or blackened when stem is split.	Waxahachie wilt.	*Fusarium sp.*, a fungus.	Rotation of crops omitting cotton; time required unknown; disease not yet studied from standpoint of control.	161

FLAX

Symptoms	Disease	Cause	Control	Page
Seedling: Damps off. *Mature Plant:* Weakened and browned; seeds become shrivelled.	Anthracnose.	*Colletotrichum lini*, a fungus.	See flax wilt.	162
Seedling: Outside of stem killed at soil line; plant withers and dries. *Mature Plant:* Outside of stem killed at soil line; stem often swollen above injury, or both above and below it; large plants break at injury and fall to ground.	Heat canker.	Physiological.	Thick seeding, early sowing; drill rows north and south.	163
Seedling: Brown spots on seed leaves, afterward on true leaves. *Mature Plant:* Leaves spotted greenish yellow to dark brown, wither and fall; small elongated brown lesions on lower part of stem extend around and upward. *Field:* Spots of brown plants not sharply delimited.	Pasmo.	*Phlyctaena linicola*, a fungus.	Burn stubble and infected straw in field immediately after harvest; do not sow flax in field where disease has occurred; disinfect seed. Argentine varieties most susceptible.	164
Plant: May be attacked in any stage. *Seedlings:* If not killed before emergence from soil suddenly wilt and dry or rot. *Older Plants:* Weaken, wilt at top, yellow, die; wilted yellowed leaves may show only on one side. *Roots:* Killed and turn ash gray; so decay that plant is easily pulled up as in Texas root rot. *Field:* Infected spots are roundish as in Texas root rot.	Wilt.	*Fusarium lini*, a fungus.	Select plump, bright colored seed and clean thoroughly; treat seed with formaldehyde, 1 pound to 40 gallons of water, applied in a fine mist with constant shovelling; leave covered 2-3 hours and shovel at least twice the first hour. Grow flax in the same field only once in 5 years; sow resistant flax and save your own seed.	166

JOHNSON GRASS

Symptoms	Disease	Cause	Control	Page
Head: Compact instead of the natural loose panicle; black spore masses replace grains.	Smut.	*Sphacelotheca sorghi*, a fungus.		168

OATS

Symptoms	Disease	Cause	Control	Page
Head: Smutted heads appear with or shortly after the normal heads; spore masses less dusty and blacker than those of loose smut; spore masses remain in head until threshed.	Covered smut.	*Ustilago levis*, a fungus.	Treat seed with formaldehyde dip, formaldehyde spray, or disinfectant dusts (pages 209, 216); use resistant varieties of oats.	168
Head: Smutted heads appear shortly before or with the normal heads; spores soon blow away, leaving bare stalk of head.	Loose smut.	*Ustilago avenae*, a fungus.	Treat seed as for covered smut; use resistant varieties.	168
	Leaf rust.	*Puccinia coronata*, a fungus.		171
	Stem rust.	*Puccinia graminis*, a fungus.	See pages 201-204	171

PEAS

Symptoms	Disease	Cause	Control	Page
Plant: Small, water-soaked spots which become dark with age, on above-ground parts of plant; seedlings fall to ground or wilt; older plants show yellowing of leaves from base of plant toward top; flowers and young pods may be killed, mature pods spotted.	Bacterial blight.	*Phytomonas pisi*, a bacterium.	Use clean seed; treat seed in solution of formaldehyde, 1 pint to 22 gallons of water, for 20 minutes, or with organic-mercury dust according to directions on package.	172
Plant: Small, roundish, brown spots on roots, stem base and cotyledons enlarge and destroy seedlings; rotting of root and base of stem kills mature plants; white fungous growth on infected spots; disease may be confused with Rhizoctonia root rot.	Fusarium foot rot	*Fusarium spp.*, fungi.	Little can be done to control Fusarium diseases of peas until resistant varieties are developed. Use of clean seed, long rotations (5 yrs.) between pea crops, proper disposal of field refuse, will aid in checking them.	173
Plant: Growth retarded, or entire plant may wilt. *Stem:* Reddish brown to chocolate, wedge-shaped spot at attachment of seed-leaves, not sunken at first; soft tissues may be destroyed; orange red to brown discoloration of wood strands may be present. *Root:* Taproot and laterals decay; taproot rotted off where connected with stem, forcing new roots above injury.	and root rot			173

Symptoms	Disease	Cause	Control	Page
Field: Scattered circular spots of sick plants vary in size, enlarge from center outward until whole field is affected. *Plant:* Bluish green becoming yellow; upper part may become rigid or may suddenly wilt and dry with green color. *Leaf:* Curves downward and rolls; withers from base of plant toward top. *Root:* Some brown discoloration on outside but mostly white and clean; yellow to orange-brown wood strands in upper part of tap root.	and wilt.			173
Vine: White mold on stems, leaves, pods, becomes powdery; diseased parts may become yellow; badly infected plants dwarfed and killed.	Powdery mildew.	*Erysiphe polygoni*, a fungus.	Too expensive; either Bordeau mixture or sulphur dust.	173
Plant: Stunting, later the leaves yellow and plant may die; small, light brown, irregular spots on base of stem and taproot which darken and become sunken; infected roots constricted; infection kills young plants; older ones survive.	Rhizoctonia root rot.	*Rhizoctonia solani*, a fungus.	Clean cultivation and destruction of weeds previous to planting, good drainage, avoidance of excess moisture; peas should not follow potatoes, cotton, or beans which have shown extensive infection.	175

PEAS

Symptoms	Disease	Cause	Control	Page
Plant: Dwarfing and yellowing; lumps or galls in the roots.	Root knot.	*Caconema radicicola*, a nematode or roundworm.	See page 154.	177
Field: Roughly circular, dead spots with margin of dying plants; white to buff mats of fungus may appear on surface of infected soil. *Plant:* May be stunted or may wilt and die more or less suddenly; dirty white fungous threads on main root which is destroyed.	Texas root rot.	*Phymatotrichum omnivorum*, a fungus.	See pages 160-161.	178

RED CLOVER

Dodder disease.	*Cuscuta sp.*, a flowering plant.		179
Powdery mildew.	*Erysiphe polygoni*, a fungus.		179
Pseudopeziza leaf-spot.	*Pseudopeziza trifolii*, a fungus.		179
Root knot.	*Caconema radicicola*, a roundworm.	See page 154.	179
Rust.	*Uromyces trifolii*, a fungus.		179

RYE

Symptoms	Disease	Cause	Control	Page
Head: Hard, black or violet bodies, up to 1½ inches long, replace some kernels of head; diseased heads shorter and lighter than normal heads	Ergot.	*Claviceps purpurea*, a fungus.	Clean seed and proper rotation of crops.	179
Leaf: Small, oval, brown spots, mostly on leaves but some on stem, at first covered, then breaking open and exposing rust-colored summer spores; later small, oval to elongated, gray spots showing dark brown to black winter spores when mature.	Leaf rust.	*Puccinia dispersa*, a fungus.	Sow resistant varieties when practicable	181
Leaf: Small, gray spots on upper surface of leaf, yellow underneath; leaf becomes yellow; spots moldy above.	Powdery mildew.	*Erysiphe graminis secalis*, a fungus.		181

SESAME

Plant: Entire plant above ground may show disease *Leaf:* Brown spots appear; leaf dies and dries out. *Stem:* Discolored dark brown to black; gray slimy bacterial ooze may flow out, dry on stem and turn black.	Bacteriosis.	*Phytomonas solanacearum*, a bacterium.	Treat seed for 10 minutes with 1:1,000 mercuric chloride solution (Poison!).	181

SESBANIA

	Texas root rot.	*Phymatotrichum omnivorum.*		183

SORGHUM

Symptoms	Disease	Cause	Control	Page
Leaf: Narrow, water-soaked streaks, short or several inches in length, which later become red; streaks may broaden into spots with red margins and tan centers; bacterial ooze on streaks dries into white or pale yellow scales; leaves and parts of leaves may become dead and dry.	Bacterial streak.	*Phytomonas holcicola*, a bacterium.	Try seed treatment	183
Leaf: Streaks and blotches, blunt or jaggedly pointed, very short to several inches in length, never water-soaked but dark purplish red, brick-red, or brownish red throughout, on leaves but may extend to stems; red or yellowish brown crusts of dried bacterial ooze on lower side of spots; part of leaf surface may be killed.	Bacterial stripe.	*Phytomonas andropogoni*, a bacterium.	Plant resistant varieties; treat seed.	183
Head: More compact and slenderer than healthy heads when grain is filling; kernels replaced by mass of dark brown to black powder enclosed in thin, whitish membrane which becomes broken and liberates the spores.	Covered kernel smut.	*Sphacelotheca sorghi*, a fungus.	Apply copper carbonate, with machine (page 214), to seed before planting or use the formaldehyde seed treatment (page 209).	186
Head: Smaller in diseased than in healthy plants; whole head, rarely a part, never single grains, smutted; smut set free by breaking of gray membrane and spores scatter leaving a fibrous mass.	Head smut.	*Sorosporium reilianum*, a fungus.	Treat seed as above; rotate crops where soil is infected, omitting susceptible sorghums and corn; plant resistant sorghums.	188

Symptoms	Disease	Cause	Control	Page
Leaf: Brown to red pustules, elongated, between the veins, scattered or grouped, and situated on bright purplish-red spots which more or less cover surface of leaf; pustules first covered, later breaking open and exposing light brown summer spores; similar pustules, deep reddish brown, shed deep brown winter spores later in season.	Rust.	*Puccinia purpurea*, a fungus.	Rotate crops.	190
	SOYBEAN			
	Root knot.	*Caconema radicicola*, a roundworm.	See page 154.	192
	Stem rot.	*Rhizoctonia solani*, a fungus.		192
	SUDAN GRASS			
See "Sorghum"	Covered kernel smut.	*Sphacelotheca sorghi*, a fungus.	See page 188.	192
See "Sorghum"	Head smut.	*Sorosporium reilianum*, a fungus.	See page 190.	192
	WHEAT			
Head: Lower third or less of glume discolored brown to black; grains under infected glumes have germ-end colored faint brown to charcoal black and may be dwarfed.	Basal glume rot.	*Phytomonas atrofaciens*, a bacterium.	Use clean seed.	192

WHEAT

Symptoms	Disease	Cause	Control	Page
Leaf: Dark, water-soaked spots turn pale yellow, later yellowish brown; shrivelling follows.				
Kernel: Brown, creosote-like discoloration over embryo and sometimes extending into endosperm.	Black point.	*Helminthosporium sativum* or *Alternaria sp.*, fungi.	None known.	194
Plant: Stunted, bluish green stems, leaves, heads.	Bunt; stinking smut.	*Tilletia tritici* here; either *T. tritici* or *T. levis* elsewhere; fungi.	Treat seed with copper carbonate dust by means of a treating machine.	196
Head: Loose appearance; dark smut balls, which consist of black masses of spores, replace grains; odor of decaying fish; smut remains in head.				
Head: Young heads show black, powdery masses at first covered with thin gray membrane but soon free; smut blows away leaving only central stalk of head.	Loose smut.	*Ustilago tritici*, a fungus.	Hot-water treatment and seed plot; resistant varieties.	199
Leaf: Scattered, round or oval pustules, mostly on upper surface, bright orange at first but becoming chocolate brown; later black pustules on under surface, flat, covered.	Orange leaf rust; brown rust.	*Puccinia triticina*, a fungus.	Use resistant varieties. Dusting with sulphur reduces loss.	200
Field: Spots of stunted, rosetted plants.	Rosette.	Virus or viruses.	Resistant varieties.	200
Plant: Dull blue color becoming brown; excessive tillering; green and yellow types of mosaic may be present; affected plant frequently killed.				

Symptoms	Disease	Cause	Control	Page
Leaf and leaf sheath: Pustules or blisters 1/16 to 3/16 inch long appear on leaf sheath and leaf, break open, and show rust-colored spores; later similar pustules develop black spores *Head:* Kernels shrivelled.	Stem rust.	*Puccinia graminis tritici*, a fungus.	Use resistant varieties when practicable. Increase in yield and quality has resulted from the application of sulphur dust to the growing crop.	201
Field: Spots of sick plants small to 15 feet across; spots have distinct margin. *Plant:* Dwarfing of all parts; roots black and brittle; bases of stems black and glistening; plants yellow at flowering time usually with bleached white heads; surviving plants yield little grain.	Take-all.	*Ophiobolus graminis*, a fungus.	Rotate with crops other than wheat for 4-5 years.	204
WHITE SWEET CLOVER; HUBAM				
	Root knot.	*Caconema radicicola*, a roundworm.	See page 154.	206
	Texas root rot.	*Phymatotrichum omnivorum*, a fungus.	See pages 160-161.	206

II. DESCRIPTIONS OF DISEASES

ALFALFA

Ascochyta Leaf-Spot *(Ascochyta imperfecta)*

A leaf-spot of minor importance is caused by the fungus, *Ascochyta imperfecta.* The disease has been found in Cochise County and may be present in other alfalfa-growing districts. The infected areas on the leaf (Fig. 1) are pale in color like those of the white spot disease (Page 127) from which they are easily distinguished by their darker margin and the presence of tiny black fruiting bodies of the fungus which are scattered over the spots. For control measures see Pseudopeziza leaf-spot, page 120.

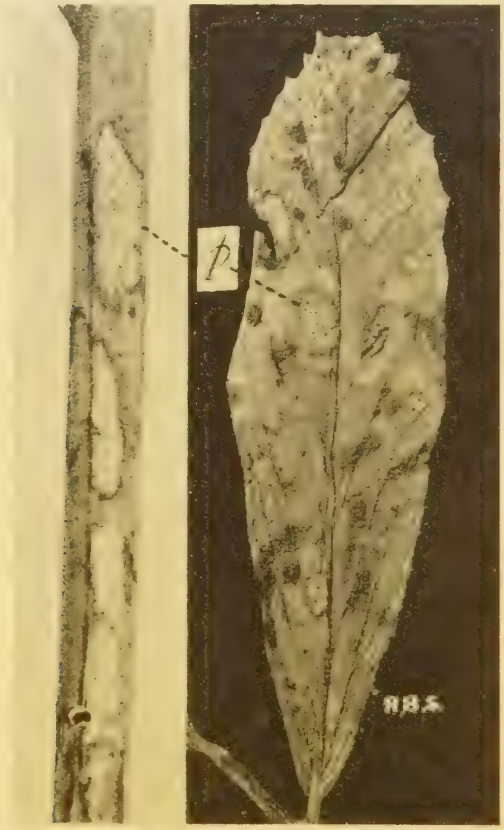

Fig. 1.—Ascochyta leaf-spot of alfalfa. Part of stem and a leaflet enlarged to show very small black fruiting bodies "p" of the fungus in the whitish lesions. x 4.

ALFALFA

Bacterial Blight *(Phytomonas medicaginis)*

The disease of alfalfa known as bacterial blight or Sackett's disease was first noticed in Colorado in 1904.[1] It has also been reported by Elliott[2] to occur in Utah, New Mexico, Nebraska, Kansas, and Indiana, although the United States Department of Agriculture gives the distribution as "general, especially in the Western States" in its check list of diseases[3]. The latter is probably a more accurate statement. We have several times reported the blight from this State, but Arizona is not mentioned by Elliott.

Symptoms

Bacterial blight of alfalfa is primarily a stem disease, although it also attacks other green parts of the plant. Affected fields are lighter green than normal; the individual plants are less juicy and spindling as compared with healthy ones, the leaflets smaller and sometimes partly folded as in dry weather. On the stems there are water-soaked, yellowish green, elongated spots, usually more numerous on the first to third joints from the soil. Similar but roundish spots may appear on the leaves and stipules. From the spots a thick, clear, somewhat sticky liquid may ooze out, run over the surface, and dry like varnish, although the bacterial ooze is less common here than in moister regions. Later the water-soaked spots turn dark brown to black (Fig. 2); the stems and other infected parts become brittle and may be lost. The attacked stems may die, or the whole plant may be killed, or the disease may apparently disappear.

The disease has been said to attack only the first cutting, but in Arizona it often remains active throughout the growing season.

Loss

Losses from bacterial blight of alfalfa are caused by dwarfing which means less hay from a given area. The brittle stems and leaves break off easily during the process of harvesting, and much of the most valuable part of the cutting is left on the ground.

Control

Early cutting of badly blighted fields has been suggested for the control of bacterial blight of alfalfa. This practice does not always produce results for, at least in Arizona, succeeding cuttings may be badly infected. However, no other method appears

[1] Sackett, Walter G.—A bacterial disease of alfalfa. Col. Agr. Exp. Sta. Bul. 158. Apr., 1910.

[2] Elliott, Charlotte—Manual of bacterial plant pathogens.—Williams and Wilkins, Baltimore, Md. 1930.

[3] Anderson, Paul J. et al—Check list of diseases of economic plants in the United States—U. S. D. A. Dept. Bull. 1366. Apr., 1926.

practicable; until strains of alfalfa are found which are resistant or immune to the disease, no better means for the control of the blight can be given.

Fig. 2.—Bacterial blight. Alfalfa stems in various stages of infection.

ALFALFA

Crown Rot

Crown rot of alfalfa[1] has been observed in the field in southern Arizona. It has also been sent in from the northeastern part of the State. This diseased condition does not appear to be extensive in Arizona.

Fig. 3.—Alfalfa plants almost dead from crown rot. Plant at left shows splitting of crown typical of early stages of crown rot. x 4/9.

[1] Brown, J. G. and Gibson, Frederick.—Brief summary of plant disease determinations—Ariz. Agr. Exp. Sta. Ann. Rept. 33: 243. 1922.

ALFALFA

Symptoms

The crowns of affected plants are rotted and discolored light to dark brown and the rotted area extends downward, chiefly in the central part of the root (Fig. 3). Plants thus affected are dwarfed and weak. No wilting was observed.

Cause

In the affected plants a species of *Fusarium* was present which showed an abundant white growth on the decayed crowns which were placed in a moist chamber. No inoculations were made. Specimens of alfalfa plants examined in summer in southern Arizona were growing in soil underlaid with almost impermeable clay at a depth of 16 inches to 3 feet; those from northeastern Arizona were sent in the spring when the soil was still wet and soft. Although the fungus appeared to be the direct cause of the rot, unfavorable conditions may have weakened the plants and made easy the fungous attack.

Deep subsoiling on a farm in the district where crown rot was first noticed resulted in a fine stand of alfalfa. This suggests that the impermeability of the clay, through which the roots could not grow, may have contributed to the diseased condition of the plants. Another possible factor is the practice of running livestock on alfalfa fields soon after a heavy irrigation. Trampling may result in split crowns which thus become easily infected by soil-dwelling fungi. In the north central and northeastern valleys, winter injury may be followed by crown rot.

Fig. 4.—Crown wart of alfalfa caused by *Urophlyctis alfalfae* (after Jones and Drechsler).

ALFALFA

Crown Wart *(Urophlyctis alfalfae)*

Crown wart, also called root gall and (improperly) crown-gall, is a disease widely distributed in the United States but rare and seldom destructive in Arizona. The disease was first observed here by McCallum[5] in 1909. It is characterized by rounded, irregular galls (Fig. 4) which vary in size from that of a pea to that of a walnut or larger. The galls develop in the crown of alfalfa, stunt growth, and sometimes kill the affected plant. Diseased plants have brown dead stems, or weak stems with yellow foliage. When cut across the galls have a mottled appearance. The causal fungus is *Urophlyctis alfalfae*.

Control

Badly diseased fields should be plowed under and planted to crops other than alfalfa for at least 3 years.

Dodder Disease *(Cuscuta spp.)*

Dodder, or *Cuscuta* as it is known to botanists, is a flowering plant which is also called "love vine." Several of the fifty or more species of dodder in the United States attack alfalfa.[6] Early in life the seedling clings to alfalfa, sinks root-like suckers into the host, and withdraws food and water from the latter, thus weakening the crop plant. By abundant branching the dodder comes to resemble a bunch of yellowish thread, hence the source of the name dodder from Friesian "dodd," meaning a "bunch" and Dutch "dot," a ravelled thread. Seeds of some species of dodder are so much like the seeds of alfalfa that they are separated only with difficulty.

Life History

Seeds of dodder germinate in soil into a slender, thread-like seedling without seed leaves (cotyledons). The seedling fastens itself to the alfalfa plant, loses its connection with the soil, and afterward grows at the expense of the host plant. It continues to branch and throw out new suckers until the attacked alfalfa is more or less entangled in a yellowish bunch of the vine. When mature the dodder vine bears clusters of small white flowers (Fig. 5). The fruits are capsules which split open by a ring; the seeds are gray to brown in color and comparatively small.

Spread

The commonest means for spreading dodder is through the use of impure seed. Hay containing dodder may spread the weed by the falling of pieces of stems, fruits, and seeds when the hauling is in progress. Men, farm animals, and implements may also carry dodder. Seeds of the parasite float in irrigation water and viable seeds are found in fresh manure.

[5] McCallum, W. B.—Plant physiology and pathology—Ariz. Agr. Exp. Sta. Ann. Rept. 20: 583. 1909.

[6] Hansen, Albert A.—Dodder—U. S. D. A. Farmers' Bul. 1161. 1921

ALFALFA

Fig. 5.—Dodder or "love vine" is an important parasite of alfalfa. It twines around the host from which water and food are obtained; finally large masses of flowers and fruits are produced. The seed is small and difficult to remove from alfalfa seed.

ALFALFA

Control

Small infested spots in the field should be mowed and burned on the spot before the flowers of dodder open; seeds cannot then be formed and any seeds which may have been left on the surface of the ground the preceding season will be killed. Burning may be necessary where large fields are badly infested. Since seeds of dodder may remain alive for five or more years, non-susceptible crops should be planted on the burned-over area. Barley, wheat, corn, cowpeas, velvet beans, and potatoes are not attacked and may be used in the five-year rotation.

In the case of small infested spots on which alfalfa is to be continued after the spots are mowed and burned, the infested area should be kept dry for some time preceding treatment. If the mowed alfalfa and dodder are not sufficient to make a hot, quick blaze, straw or old alfalfa hay should be spread over the infested spot. A quick fire will not kill the roots of alfalfa, so that the ground is soon covered with a healthy growth.

Downy Mildew *(Peronospora trifoliorum)*

Downy mildew is a widely distributed foliage disease which may be injurious to alfalfa under conditions favorable to the causal fungus, although it has never been serious in Arizona.

Fig. 6.—Downy mildew of alfalfa appears on the leaflets in early spring and during the summer rains. It causes yellowish spots covered with a whitish to gray-violet fungous growth. ×1

Symptoms

During the early spring months and the season of summer rains the upper surface of affected leaves shows light green or yellow-green spots (Fig. 6). On the under side of the spotted

leaves is a grayish, downy growth which becomes a pale violet with age. The growth is composed of filaments bearing thousands of small, egg-shaped spore cases of the fungus, *Peronospora trifoliorum*. Since the spore cases break open in drops of dew or rain, thus setting free small, delicate, swimming spores which reinfect the leaves, spread of downy mildew is dependent upon moisture. Control measures are rarely necessary, for the disease disappears with the arrival of hot dry weather. When control is desirable the procedure given for Pseudopeziza leaf-spot should prove effective.

Girdle *(Stictocephala sp.; Coccus hesperidum)*

Although alfalfa girdle is caused by insects, it is included here because it is often attributed to unfavorable cultural conditions or practices, or to parasites which are plants. Girdle was first reported by McCallum[1] of this Station in 1909, who attributed the cause to a species of *Phoma*. About the same time Dr. C. W. Edgerton of Louisiana showed by experiment that girdle is caused by *Stictocephala* and brought the disease to the attention of Osborn[2]. Brown and Gibson[3] reported the disease as serious in southern Arizona, gave a more complete picture of the symptoms, and observed the development of girdle as a result of the activities of the scale, *Coccus hesperidum*. They also found the disease on numerous wild plants. Although they isolated fungi and a bacterium in cultures, none of the organisms produced girdle when inoculated into healthy plants in later work. Since McCallum made neither cultures nor inoculations; *Phoma* is absent from girdled tissues oftener than present; and since *Stictocephala* and *Coccus* have been found capable of producing the disease, we are satisfied that the insects are the cause. Of the two insects, *Stictocephala* is much more numerous than *Coccus;* we believe that it is the important causal agent.

Symptoms

The first symptom of girdle is a slight enlargement on the stem of alfalfa which can be located with the finger tips before it can be seen. Very soon a slightly sunken band of light green appears which widens and becomes gray-green. Occasionally the band is spiral rather than circular. The leaves at the top of the attacked plant become purpled, then yellow, or the color changes may be purple to red then later yellow. The stems may also be purple or reddish green from the tip downward to the girdle, with normal green below. Eventually the stem dies. Girdles

[1] McCollum, W. B.—Plant physiology and pathology.—Ariz. Agr. Exp. Sta. Ann. Rept. 20: 583. 1909.

[2] Osborn, Herbert.—Economic importance of Stictocephala.—Jour. Econ. Entomol. 4: 137-140. 1911.

[3] Brown, J. G. and Gibson, Frederick.—Some observations on alfalfa girdle.—Phytopathology 12: 188-190. April, 1922.

usually are found near the soil line, but they may appear anywhere on the stem (Fig. 7). When they are near the base of the stem, a thickened mass of tissues forms just above the injury. The swelling appears to be due to interference with the downward movement of elaborated food in the phloem region induced by the girdle. Epidermis covers the shrunken band. Numerous weeds are attacked by the insects and show identical girdled tissues.

Fig. 7.—Alfalfa girdle, A, on base of stem (g) with collar above, B, higher on stem: b, spiral girdle; c, ring girdle; d, later stage of c.

Distribution

Alfalfa girdle causes considerable loss in Arizona where the crop is sometimes so dwarfed and thinned that entire fields are plowed under. Girdle also occurs in California, Colorado, and states farther east. Besides Edgerton's citation[1] listing Louisiana, Horsfall[1] has reported girdle from New York and Arkansas. It has been seen in southern Michigan by the senior author of this bulletin. Probably girdle is much wider distributed than is realized at the present time.

[1] Horsfall, James G. A study of meadow-crop diseases in New York. Cornell Agr. Exp. Sta. Mem. 130. Oct., 1929.

ALFALFA

Control

No control measures for girdle are known. Since the disease in Arizona is often worst in fields bordered by weed-covered, wild and uncultivated areas, it is supposable that the insects which cause the trouble migrate from the less attractive food plants to the more succulent alfalfa. So far as we know, the effect of mowing and burning weeds surrounding alfalfa fields on the prevalence of girdle in the alfalfa has not been determined. It has been suggested that the eggs of *Stictocephala* may be laid in the tissues of the alfalfa plant. In that case withholding irrigation and drying the soil for a time followed by mowing and burning the crop might give a new cutting comparatively free from girdle. The problem belongs to the entomologists rather than to plant pathologists. We are unable to find even a statement of the egg-laying season of the insect, which must be known before proceeding with directions for control.

Pseudopeziza Leaf-Spot *(Pseudopeziza medicaginis)*

Almost universally present in alfalfa fields Pseudopeziza leaf-spot is the most important, often the only important, foliage disease of the crop. Although leaf-spot rarely kills affected plants, the loss in their vigor and in the quality of the hay caused by the shedding of leaves is considerable. Since much Arizona hay is now sold under federal hay grades which place a premium on leafiness, the effect of leaf shedding is directly reflected in the lower market prices.

Fig. 8.—Pseudopeziza leaf-spot on alfalfa. The small, brown, slightly raised spots are present on both sides of the leaf. x 2.

ALFALFA

Symptoms

Unless infection is severe the spots are not apparent until the alfalfa plants are parted to expose the lower leaves which seem to be most susceptible. The second or the third cutting is worst attacked under Arizona conditions, although leaf-spot may reappear in the fall cuttings. The causal fungus produces small, brown, circular spots (Fig. 8) approximately one-sixteenth inch in diameter which are visible from either the upper or the lower surface of the leaf. Severely infected leaves turn yellow, excepting a green zone around the spot, and fall off. Some spots may also appear on green stems. Upon careful examination the center of a spot shows a small, raised disc in which the spores of the fungus are produced. The fungus overwinters on dead leaves and stems; it is probably not carried by the seed unless present on fragments of infected leaves.

Control

Practical control measures are limited to the following: (a) when the leaf-spot appears just before cutting time mowing should be hastened a few days in order to avoid extensive leaf shedding; (b) badly diseased plants at any stage of growth should be mowed in order to produce new shoots free from leaf-spot.

Pseudopeziza leaf-spot is favored by a moist atmosphere; it is also prevalent on weak plants in dry soils under unfavorable conditions for growing alfalfa.

Rust *(Uromyces striatus)*

Rust of alfalfa is common in North America and Europe, and the disease is also found in South America and Australia. The rust attacks some other species of Medicago.[11] This disease apparently causes greater losses in the warmer parts of the United States than in the cooler states. In Arizona, in irrigated fields, usually there is enough moisture for the development of the disease on the lower leaves of alfalfa plants; in dense stands spotted leaves and stems may be abundant.

Symptoms

Reddish brown to cinnamon-colored spots appear on either surface or both surfaces of the leaf and on the stem (Fig. 9). The spots are roundish on the former and elongated on the latter. At first they are raised places in the skin or epidermis which are caused by the upward growth of groups of spores, but later the covering breaks and the spores under the spots are exposed. After exposure the spores rub off on the fingers in the form of a rusty powder. The first spores to appear in a spot are the "summer" spores; they serve to quickly spread the rust disease over

[11] Arthur, J. C.—Plant rusts—New York. 1929.

the field. In one instance the summer spores carried the disease a half-mile in two weeks.[2] Later in the season a second kind of spore, the "winter" spore, appears on the foliage in spots much like the clusters of summer spores but darker brown in color.

Fig. 9.—Alfalfa rust. A. Part of badly rusted, mature plant. B. Alfalfa leaflet enlarged to show raised masses of powdery rust spores. x 4.1.

Another infrequent symptom noticed in connection with the alfalfa rust in Arizona is hypertrophy or overgrowth of plant

[2] Pammel, L. H. and King, Charlotte M.—Four new fungous diseases in Iowa—Iowa Agr. Exp. Sta. Bul. 131. April, 1912.

parts. The affected plant may become so deformed that it is not recognized. Such deformed plants have been sent to us for identification by alfalfa growers who thought that they had found a strange weed in their fields. Furthermore, infected pods often produce a variety of sizes of seeds, some abnormally large, some normal, some small or dwarfed. Clumps of seeds held together by a gummy substance are not uncommon. Inspection of deformed alfalfa plants and plant parts, as well as abnormal seeds, has almost invariably disclosed only the rust parasite.

Control

The control measures suggested for Pseudopeziza apply to rust.

Texas Root Rot *(Phymatotrichum omnivorum)*

Texas root rot (also called cotton root rot, Ozonium root rot and Phymatotrichum root rot) causes more damage to alfalfa fields in this State than any other disease; in numerous districts it causes more loss than all other alfalfa diseases combined. Every year many fields, both new plantings and old, are plowed up because the stand has been ruined. Since there is no known practical control for the disease at the present time except rotation with resistant crops which are limited in number and kind, the indirect loss due to restricted use of land is much greater than the direct loss to any crop.

Symptoms

The disease is generally recognized by alfalfa growers who are familiar with the dead areas which increase in size as the season advances. The newly infected plants make an apparent recovery whenever the field is cut and irrigated, for the injured roots are then able to supply food and moisture to the reduced tops. A typical root-rot spot (Fig. 10) is roughly circular with only a few scattered surviving plants which are stunted. At the margin of this area is a zone of dead and dying plants, and beyond these are apparently healthy plants. If the latter are dug up, however, it will be found that the infection has already reached the tap roots of plants from 1 to 3 feet beyond the last wilted plant.

The first visible symptom of the root rot, in addition to the whitish to buff strands of the fungus on the surface of the roots (Fig. 28), is a number of small, brown, slightly sunken spots on the roots of the alfalfa plants. The length of time between infection and death of the sick plant varies greatly with soil temperature and soil moisture, the death rate being greatest in July, August, and September.

Alfalfa plants which have apparently survived the attack of root rot and have been carefully dug out, in all cases thus far observed, have a taproot which has been killed. Such plants depend entirely upon one or more lateral roots in normal position, or upon a lateral which has turned downward and become

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Fig. 10.—Alfalfa field showing spread of Texas root rot from numerous centers of infection.

in effect, a taproot. Infected plants have been found which have lost this "taproot" through the rot disease no less than five times (Fig. 11).

Fig. 11.—Crown and root system of alfalfa plant which has survived successive attacks of the root-rot fungus. The numbers 1 to 5 indicate the stubs of roots in approximately the order in which they were killed. The plant was apparently healthy when dug.

Occurrence of the buff-colored spore mats (Fig. 12) on an area infected with Texas root rot also aids in the identification of the disease. The spore mats, which are formed in July, August, and September, at times when the soil moisture is abundant, are usually found in shady places on the margin of infected areas. They are at first pure white and cottony and turn to a buff powder in two days.

Control

See Cotton, pp. 160, 161.

References

See Cotton, p. 161.

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Fig. 12.—Spore mats of the Texas root-rot fungus on margin of infected area in alfalfa field. x 2/13.

Violet Root Rot *(Rhizoctonia crocorum)*

Violet root rot of alfalfa may be serious under some conditions, although it is not a disease of major importance. It was probably introduced into the United States from Europe where it has been known for over two hundred years. In this country[13] it is found in the Pacific Northwest, Mississippi Valley and some eastern states, and in Arizona.

Symptoms

In field symptoms violet root rot somewhat resembles Texas root rot. Infected alfalfa fields show roughly circular areas with dead plants in the center surrounded by a ring of wilted and dying plants; beyond these are newly infected plants which show a decided yellowing of the foliage. The circular areas advance from 3 to 20 feet per year. Roots of infected plants are more or less covered with a mat of violet fungous threads and often show numerous small infection cushions. The deep violet strands are quite striking and easily distinguished from the buff strands of the Texas root-rot fungus. Infected plants usually die within a short time; the few that survive are not vigorous. The taproot and often all laterals are rotted off.

[13] Faris, J. A.—Violet root rot *(Rhizoctonia crocorum DC)* in the United States—Phytopathology 11: 413-423. 1921.

ALFALFA

Cause

Violet root rot is caused by a soil-inhabiting fungus, *Rhizoctonia crocorum*, also called *Rhizoctonia violacea* and *Rhizoctonia medicaginis*,[14] which penetrates the uninjured bark of alfalfa roots, kills the tissues, and results in the death of the plant.

Relation to Environment

The disease occurs in both humid and semi-arid districts and in both sand and loam soils. There is some evidence that it develops best at high temperatures.

Control

The parasite is a typical soil fungus not easily controlled because it can live on dead organic matter as well as on the roots of many living plants. Rotation with crops other than alfalfa is the only practical control for badly infected fields. In rotations the sweet potato, which is also susceptible to violet root rot, should be avoided. Fields with a few small spots can be freed from infection by disinfecting the soil according to instructions given on pages 218-221 of this bulletin.

White Spot

A rather conspicuous leaf-spot which sometimes causes injury to alfalfa is very aptly called "white spot." This malady occurs throughout the United States but it is more prevalent in the Rocky Mountain region, particularly in Utah. It has not been serious in Arizona.

Symptoms

Pale, almost white spots (Fig. 13) of variable size appear on the leaves, usually at the margin or tip, or between the veins. The spots may occur at any time during the growing season.

Cause

O'Gara[15] suggests that a combination of a too concentrated soil solution and conditions optimum for transpiration result in the withdrawal of water from the leaves faster than it can be replaced by the roots, thus causing a drying of the leaf tissues. Alkali or excess of other soluble salts in the soil reduce absorption of water by the alfalfa, while drying winds greatly increase the transpiration. On the other hand Richards and Blood[16] suggest that the disease may be caused by a toxin injected into the

[14] Duggar, B. M. —*Rhizoctonia crocorum* (Pers.) DC. and *R. solani* Kühn with notes on other species—Ann. Mo. Bot. Gard. 2: 403-458. 1915.

[15] O'Gara, P. J. —The white-spot disease of alfalfa.—Science 48: 299-301. 1918.

[16] Richards, B. L. and Blood, H. L. —Psyllid yellows of the potato.—Jour. Agr. Res. 46: 189-216. 1933.

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plant during the feeding operations of certain insects. It is of interest that the plants affected are often the largest and apparently the most vigorous in the field.

Fig. 13.—White spot of alfalfa, a physiological disease which is more conspicuous than injurious in Arizona.

Control

Until the cause of white spot of alfalfa is certainly determined, no definite method can be recommended for the control of the disease. Maintenance of proper soil moisture and avoidance of an accumulation of alkali have been suggested but not proved to prevent the disease.

BARLEY

Covered Smut *(Ustilago hordei)*

Covered smut of barley is much more serious than loose smut and appears to be increasing in Arizona. The fungus which causes the disease is *Ustilago hordei*. Unlike loose smut, the fungus can infect only the young barley seedling[17] and not the flow-

[17] Fischer, E. and Gäumann, E.—Biologie der pflanzenbewohnenden parasitischen Pilze—Jena, 1929.

er. There is then only a short period in the life of the barley plant when it can be infected with covered smut.

Although the covered-smut fungus *looks* the same wherever it is found, it really consists of several strains just as the Leghorn and other kinds of poultry embrace several strains. The strains of the loose-smut fungus may be separated by trying them out on different varieties of barley. For instance Faris[1] found that one strain of covered smut (Form IV) would not attack Nepal, Hannchen or Summit barleys, but would cause smut in Texas Winter Barley; another strain (Form II) attacked only Nepal Barley and did not infect the other varieties mentioned. This knowledge obtained in research on barley smut is valuable. It explains why a barley variety may be resistant to covered smut in one grain district and attacked by covered smut in another district. Also in breeding a smut-resistant barley for a given district it is important to determine what strains of smut are likely to be present in that district. A variety of barley advertised as smut-resistant in Wisconsin or Pennsylvania may prove to be smut-susceptible in Arizona, because here there may be entirely different strains of the covered-smut fungus.

Symptoms

Covered smut of barley shows smut masses (Fig. 14A) under a silver-gray skin or membrane, which replace the grains in a head and which appear a few weeks *after* flowering time. Although the membrane may become cracked and broken, the purplish black spore masses remain in the head until the barley is threshed; then many of them are broken and the spores are dusted over the grain.

Control

Since the spore masses of covered smut may remain mixed with the seed barley after threshing, the grain should be thoroughly cleaned either at the elevator or at home with a fanning mill. There will be left after the most careful cleaning a fine dust of spores over the surface of the grain, and when the grain is sowed the spores germinate and infect the seedling as previously stated. To kill the smut spores the seed barley must be disinfected. For treating the grain disinfectant dusts are handy to use and some dusts are very efficient. Ceresan, an organic-mercury compound, is one of these. The dusts can best be applied by using a machine which may be home-made (see pages 214-215); otherwise coverage is likely to be poor which results in wasted effort.

The prevalence of covered smut is greater under conditions of soil, moisture and temperature which check the growth of barley

[1] Faris, James A.—Physiological specialization of *Ustilago hordei*. Phytopathology 14: 537-557. December, 1924.

Fig. 14.—Smuts of barley: A. Covered smut; B. Loose smut; C. Healthy head for comparison. x 1.

When it is remembered that infection can occur only between the breaking of the seed coat and the growth of the first leaf, this is easy to understand. The slower the germination of the grain, the longer is the seedling in condition for infection. Conversely, anything which hastens growth, such as the wise use of irrigation water and the application of beneficial fertilizers, operates to shorten the time required for the susceptible early seedling stage and thus to reduce infection.

Hulls on the barley grain have been shown to protect against infection with the smut fungus. The hulls are often broken or even entirely removed in threshing. Reduced speed in operating threshing machines when seed barley is threshed probably would result in less infection with covered smut when such seed is sowed.

Loose Smut *(Ustilago nuda)*

Loose smut has been known and studied for many years. Its cause is the fungus, *Ustilago nuda*. The fungus ripens its spores while the barley is still flowering. The spores are borne away by the wind and those which fall on the flowers of healthy barley plants soon germinate. To do this the spore sends a very small tube into the flower. This tube eventually reaches the young kernel where it branches repeatedly but does not prevent the kernel from filling. When the barley grain is planted the next season the smut fungus inside the grain grows into the seedling barley plant, is carried upward, and causes the head of the mature plant to be smutted.

Symptoms

Loose smut of barley can easily be told from the other barley smut called covered smut. Loose smut shows at the *beginning* of flowering time; covered smut a few weeks *after* the barley begins to flower. Although the masses of loose smut spores (Fig. 14B) are covered at first, the covering soon breaks and the spores are scattered, leaving only a bare stalk. Covered smut, on the other hand, retains its spore masses after the head is ripe.

Control

Until recently it was believed that the loose smut of barley is always inside the grain, and that spores of the loose smut fungus clinging to the outside can not cause infection. If this were true only the hot-water method for disinfection of the grain would reduce the amount of loose smut when the grain is treated. However, it has been found that the spores which ride *on* the grain may cause infection. In loose smut then there are two conditions of the barley grain: some grains have the smut parasite *inside* and some grains carry the spores *on the outside*. Only the hot-water treatment can be successfully used to kill the parasite in-

side the grain, but disinfectant dusts like Ceresan will kill the spores of loose smut on the outside of the grain.

Since loose smut is never abundant here; the hot-water treatment is slow and requires special equipment for handling large quantities of grain; and since disinfectant dusts which are satisfactory for covered smut also reduce loose smut by killing surface-borne spores on the grain, we recommend the use of dusts, especially Ceresan. The exception is seed barley for seed plots. By using the hot-water method a small quantity of barley grain can be thoroughly disinfected; when sowed in an isolated seed plot the increase in clean seed can be used for planting a commercial crop.

Powdery Mildew *(Erysiphe graminis)*

Powdery mildew, when it is present, usually occurs on fall-planted grain during March and April; it is severe only when these months are wet. The disease often accompanies rusts, for the rust fungi are likewise favored by moist weather. Although powdery mildew of barley usually is a minor disease it has seriously injured some fields in wet springs.

Symptoms

Infection typically appears first on the older leaves on which white patches of mycelium produce a powdery, white mass of spores. As the mycelium grows older it becomes weathered and grayish in color. In the northern states where powdery mildew is abundant on fall-sown and volunteer barley, the fungus produces dark brown to black fruiting bodies about one-fiftieth inch in diameter which contain resting spores and enable the fungus to survive the winter. Resting spores of the barley powdery mildew are rarely seen in southern Arizona where the winters are mild. This and other powdery mildews are interesting because they develop almost entirely on the surface of plants; most of them penetrate only the first layer of host cells for anchorage, food and water.

Control

The destruction of possible host plants of powdery mildew, including wild grasses and volunteer barley, would largely eliminate the source of infection. Dusting with sulphur is effective and should be practiced when the cost of material and labor permits.

Rusts *(Puccinia graminis; Puccinia simplex)*

Barley is quite susceptible to two different rusts, the black stem rust *(Puccinia graminis)* which attacks wheat, oats, and grasses, and a barley leaf rust *(Puccinia simplex)* which forms small, yellow pustules on the leaves. The stem rust is common and destructive on barley in Arizona in moist "rust years" and

uncommon in dry seasons. The leaf rust is rare and of no commercial importance. See "stem rust," pages 201-204, for details of symptoms, life history, and control of *Puccinia graminis*.

Stripe (*Helminthosporium gramineum*)

Barley stripe, a fungous disease caused by *Helminthosporium gramineum*, has appeared sporadically in Arizona causing some serious losses. In 1926 one forty-acre field showed 20 per cent dead plants. Since severe infections occur only in fields planted with seed imported from states where stripe is prevalent, it appears that our climatic conditions are not favorable to the establishment of this disease.*

Symptoms

The first symptoms are seen in the seedlings which show long, pale or yellowish stripes varying in length from a half-inch to the entire length of the leaf blade. The stripes soon develop a dark brown discoloration and increase in size, involving the whole leaf and stem. The dead tissues become brittle and split easily, giving to the diseased plant a broken and frayed appearance. The height of affected plants is about one-half normal, and the spike usually does not appear at all or only partly emerges from the boot (Fig. 15). The awns are distorted, the spike develops a decidedly brownish tinge, and viable seeds are rarely produced.

The disease is fully developed at blossoming and the plants become so weathered by harvest time that the stripes are seldom noticed. The infected parts show dark areas which are caused by abundant spore production in those regions (Fig. 15c). The spores are carried by wind to the healthy spikes and the seed is soon contaminated. Infection of the seed may persist from three to five years. When the seed germinates the tissues of the seedling are immediately infected and the growth of the fungus keeps pace with the growth of the plant, although no external symptoms are visible. This life history, including the appearance of the spores about flowering time, forms a striking similarity to the life history of the systemic diseases such as covered smut of wheat.

*A report received since this description was written, on experiments with stripe, supports the statement: "In studying the influence of incubation temperature upon stripe development, the highest percentage of disease occurred at 20 degrees C. (68 degrees F.) when inoculated seedlings were incubated four days at all temperatures and later grown in a greenhouse at 16 degrees C. (61 degrees F.). The greatest percentage of stripe developed at the lower temperatures when inoculated seedlings were incubated until reaching approximately the same stage of development at each temperature and later grown in a greenhouse held at 16 degrees C."—Shands, H. L. Temperature studies on stripe of barley. Phytopathology 24: 364-383. April, 1934.

BARLEY

Fig. 15.—Barley stripe affects leaves, stem and head. Compare healthy head, left, with infected head, right. Note stripe lesion on leaf at c. x $\frac{1}{2}$.

Control

Rotation is advisable where stripe has appeared in a field. The disease can be avoided by using seed from a field known to be

BARLEY

free from stripe. The Wisconsin Experiment Station[19] has developed two promising resistant varieties of barley, Pedigree Number 38 and Number 39, but their adaption to conditions in Arizona has not been tested.

The stripe disease is very satisfactorily controlled by several seed treatments. Brentzel[20] finds that a two-hour soak in formaldehyde solution (1 pint to 40 gallons of water) gives effective control with some danger of seed injury, and that the treatment is a slow and troublesome process; he recommends Ceresan dust, 3 ounces per bushel of seed. As a result of five-year tests of more than seventy-five fungicidal dusts, Leukel, Dickson and Johnson[21] find Ceresan and Höchst dusts most effective, although Du Pont Number 35 and DuBay Number 655 and Number 665 dusts were almost as good. Germisan (0.25% solution for 1 hour) gives almost perfect control.

BROOMCORN

Covered Kernel Smut *(Sphacelotheca sorghi)*; Loose Kernel Smut *(Sphacelotheca cruenta)*

Broomcorn, a type of sorghum grown for the broom straw made from its heads, is moderately susceptible to both kernel smuts of sorghum (Pages 186-188), the covered kernel smut being the more common in Arizona. The crop is also susceptible to bacterial stripe (Page 183-186). Very little broomcorn is grown in the State at present, therefore an estimate of losses would be inconsequential.

CORN

Bacterial Stalk Rot *(Phytomonas dissolvens)*

Bacterial stalk rot of corn has been reported[22] from this State in which it has been observed three times, and also from Arkansas, Illinois, Louisiana, Mississippi, New York, North Carolina, North Dakota and Ohio. Under conditions favorable to the disease much damage may result.

Symptoms

The disease affects the stalk and leaves. The stalk rots at one of the lower joints or nodes (Fig. 16), usually at the first node above the soil, and tips over. The rotted tissues are light to dark brown, sunken, and often have a water-soaked margin; later the lesion is fibrous because the bacterium destroys the soft tissues and leaves the woody fibers. Earlier in its development the in-

[19] Drechsler, Charles—Some graminicolous species of Helminthosporium: 1—Jour. Agr. Res. 24: 650-656. 1923.

[20] Brentzel, W. E.—Barley stripe controlled with Ceresan.—N. D. Agr. Exp. Sta. Bul. 233, p. 98. 1930.

[21] Leukel, R. W., Dickson, J. G., and Johnson, A. G.—Effects of certain environmental factors on stripe disease of barley and the control of the disease by seed treatment—U. S. D. A. Tech. Bul. 341. 1933.

[22] Brown, J. G. and Gibson, Frederick—Brief summary of plant disease determinations—Ariz. Agr. Exp. Sta. Ann. Rept. 33: 243-246. 1922.

Fig. 16. — Bacterial stalk rot, lesion at "l"; in later stages the plant bends from the lesion to the ground.

fected node is water-soaked. Only the lower leaves are affected. The leaf sheath decays, then the whole leaf withers and turns brown.

Cause

The rot is caused by a white bacterium which can enter through the water pores (hydathodes), stomata, through the openings formed by the exit of the brace roots, and through injuries caused by insects.

Conditions Which Favor the Disease

Conditions which favor the rapid growth of corn also favor the development of bacterial stalk rot. The disease is worst in moist, hot weather. Below an air temperature of 68 degrees F. there is no infection; between 68 and 77 degrees F. infections are few; at 86 to 95 degrees F. infections are most numerous. The high humidity which prevails in irrigated fields of corn when the crop is waist-high or taller is an important factor favoring infection. Closely planted (drilled) corn is more extensively attacked than "listed" corn, if one may judge from the few infected fields observed here.

Susceptible Varieties

Varieties of field corn reported susceptible to bacterial stalk rot are Biggs, Boone County White, Boone County Special,

[21] Rosen, H. R.—Further observations on a bacterial root and stalk rot of field corn—Phytopathology 11: 74-79. 1921.

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Gamble, Hastings, Huffman, Johnson County White, Mexican June, Mosby, Neal Paymaster, Nectar, Reid's Yellow Dent, St. Charles White, St. Charles Yellow, Surecropper, U. S. Selection 77, U. S. Selection 201, Webb Watson; susceptible varieties of sweet corn[24] are Country Gentlemen, Golden Bantam, and Stowell's Evergreen.

Control

So far as the authors are aware, no control is known for the bacterial stalk rot of corn, nor is the source of infection certainly known. Where the rot has caused loss, rotation with crops other than corn and planting in listed rows to avoid dense stand might prove worth while as means for controlling the disease, although its appearance in Arkansas on land which had never grown corn apparently makes doubtful the value of rotation.

A Fungous Disease Which Resembles Bacterial Stalk Rot

During the past season (1933) there has been observed in Arizona an extensive rotting of the lower nodes of corn which can scarcely be distinguished from bacterial stalk rot. Numerous cultures of the infected tissues were made from which a species of Phytophthora fungus was isolated. Inoculations of healthy corn plants with the fungus resulted in the water-soaking symptom of bacterial stalk rot without subsequent fall of the plant to the ground. The inoculated plants were in a small plot, much less protected from dry winds than naturally infected plants in the field; perhaps less extensive rotting in the former is thus explained. The Phytophthora fungus isolated from corn is undergoing study at the present time.

Cob Rots and Seedling Blights

The dry rots of the corn ear caused by *Diplodia* and *Gibberella*, which are among the most common and destructive diseases in the Corn Belt[25] and in the southern states,[26] have not yet appeared in Arizona. Our seed corn, however, frequently is infected with several fungi, principally species of Fusarium, which accounts for many "skips" in rows that reduce the yield of the crop.

Seedling Blight

Seed corn tested in a germinator often shows many infected kernels which develop white to pinkish or purplish fungous growths and discoloration of parts of the grain itself (Fig. 17). When such seed is planted in the field the young plant never

[24] Rosen, H. R.—Bacterial stalk rot of corn.—Phytopathology 16: 241-267 1926.

[25] Branstetter, B. B.—Corn root rot studies—Mo. Agr. Exp. Sta. Res. Bul. 113. Nov., 1927.

[26] Eddins, H. A.—Corn diseases in Florida—Fla. Agr. Exp. Sta. Bul. 210 Jan., 1930.

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emerges, or dies while it is quite small. Infection is often found on the young shoot above the seed rather than on the roots. The corn root rots of the Corn Belt states are frequently caused by a Pythium-like fungus.

Fig. 17.—Sprouting corn grains of Mexican June variety which were internally infected with *Fusarium*. The fungus "f" on the grains is pink; at "r" root rot has started.

CORN

Infected Ears

Although Fusaria and other organisms may be borne on the surface of the seed, they are usually embedded in the tissues near the embryo-end of the seed. Infection occurs during the ripening of the ear and is favored by abundant moisture following summer rains.

Control

Seed Selection Growers who obtain high yields of corn find it advisable to select their seed with great care. The preferred method is to hand-select ears from the best plants in the field before harvest; shuck and dry them on racks; discard all moldy, off-type, and dull colored ears; test the germination and discard ears germinating less than 80 per cent. Selected seed gives an even stand of vigorous, healthy plants and consequently higher yields.

Hand Selection vs. Rag-doll Germinator Results, which are for all practical purposes comparable to the more laborious rag-doll germinator tests in which ten kernels from each ear are germinated, can be obtained by the selection of the best ears from a lot by a method described in a circular[27] of the Missouri Experiment Station. If the following directions are carefully followed practically all seed-borne diseases will be eliminated: (a) select ears that are firm and heavy, with bright, plump kernels; avoid light ears and ears that are easy to twist; (b) select ears with no visible signs of molds; avoid white, gray, pink, red or other colored molds on the ends and other parts of the ear; (c) select ears with clean white, bright butts where the shank has broken from the cob; avoid discolored butts; (d) select ears with clean, bright cob tips; it is not so important that the tips shall be covered with kernels; avoid ears with moldy or badly discolored cob tips; (e) avoid ears whose kernels break near the tip when pulled from the cob; avoid ears with loose kernels and kernels whose tip caps break off.

Seed Treatment In the past fifteen years dust treatments have entirely replaced wet treatments for controlling seed-borne diseases of corn.[28] The dust fungicides now in use are organic mercury compounds which are slowly soluble. Among the commercial brands which have been found satisfactory are Improved Semesan Jr., Bayer Dust, Sterocide, Merko and S. F. A. 225.

The dry, shelled corn is treated with dust just before planting. About 2 ounces of dust per bushel of seed are used (follow directions on the package) and the seed and dust are mixed in a tight container until every seed is *thoroughly* coated with the dust. A

[27] Eddins, H. A.—Corn root rot.—Mo. Agr. Exp. Sta. Circ. 117. 1924.
[28] Koehler, B. and Holbert J. R.—Results of seed-treatment experiments with yellow dent corn—U. S. D. A. Tech. Bul. 260. Dec., 1931

drum for treating wheat with copper carbonate (Pages 213-216). a barrel churn, or a milk can slowly rotated for five minutes will distribute the dust effectively.

Mercury dusts are *very poisonous* and should not be inhaled. A wet cloth should be tied over the mouth and nose when seed is dusted and when dusted seed is handled. Treated seed should be labelled "poison" and kept out of reach of poultry, livestock, and children.

Common Smut *(Ustilago zeae)*

Common smut of corn occurs wherever the crop is grown. The disease is bad in Arizona where the dry air is favorable for its prevalence.[25] First recorded in America in North Carolina in 1822, corn smut has been much studied, but only recently has a possible practical control been found in the form of resistant strains of maize.

Symptoms

Pale glistening swellings may appear on any part of the plant above ground, but they are commonest on the tassel and the ear. The swellings enlarge, break open, and expose a black mass of spores (Fig. 18). For the spore masses and their silver gray covering membrane the name "smut boil" is used. On the ear the boils are largest, often several inches in diameter; on leaf, tassel, and sometimes on the brace roots, they are an inch or less in diameter. Young plants are seldom infected, but when attacked they are stunted or killed. Corn plants with large galls may fail to bear ears.

Infection

The dark spores set free by the broken smut boils are spread by wind, rain, irrigation water, and by animals. In spore masses in the soil they may remain alive for several years. When conditions are right for their germination, the spores sprout and develop smaller spores called "conidia" which infect the corn plant. The conidia are carried by wind and must reach a moist, tender surface on the corn plant before they can start the fungus of the smut disease. Favorable places for entry of the fungus into the plant are the stalks at the base of the leaf sheath, the silk, growing tassel, and wounds. Ears which are well covered by tightly wrapped husks are less susceptible to smut,[26] and vigorously growing plants are smutted worse than less active ones.

Control

In small, isolated corn fields the smut galls or boils should be collected and burned before they break open and scatter their

[25] Immer, F. R. and Christensen, J. J.—Influence of environmental factors on the seasonal prevalence of corn smut—Phytopathology 18: 589-598. July, 1928.

[26] Kyle, C. H.—Relation of husk covering to smut of corn ears—U. S. D. A. Tech. Bul. 120. 1929.

spores. Unless it is isolated a field may not be protected from smut by the destruction of the boils, for the spores may enter the crop from a neighboring smutted field. Community campaigns against corn smut can accomplish much when they cover a three- or four-year period.

Fig. 18.—Common smut of corn in tassel and in ear. The leaves and stalks may also show "smut boils."

Large smutted fields should be cultivated with a rotation of crops in which corn is used not oftener than once in a period of three or four years. The new corn field should be as far as possible from the site of recent corn crops. A corn crop which shows excessive smut may be cut before the galls open and stored in the silo where the spores are killed. Seed treatment is a waste of time for the spores of smut may be carried from the soil and cause infection at any time during the growing season.

Resistant varieties and strains of corn constitute the most practical means for controlling common smut. Silver King, Numbers 67 and 72, and Rustler Number 35 are highly resistant to smut in the field. The resistance may be due to a soluble substance in the juice of the tissues and to other unknown factors. Probably in time varieties of corn similarly resistant to smut but adapted to the semi-arid Southwest will be developed by plant breeders.

CORN

Smut and Livestock

Two questions are treated under this heading: "Will manure from stock fed on smutted corn fodder carry the smut to the field?" and, "Will smutted corn fodder injure stock?"

Although the passage of smut through the digestive tract of stock kills the spores or renders them incapable of germinating, barnyard manure is likely to contain smut boils which have been trampeled rather than eaten. Manure from stock fed on corn fodder other than silage may spread common corn smut to the fields.

Corn and sorghum smuts were fed to cattle and horses by Melchers and Ficke who observed no injurious effect. According to Stevens[31] young boils of common corn smut are good food for man, with much the same flavor as mushrooms when cooked. These statements are evidence that the smut is not poisonous.

Damping-off *(Rhizoctonia sp.)*

Damping-off is a general term used to describe the sudden death of seedling plants, either in the field or in a hot-bed or greenhouse. There are no less than five distinct fungi which are important causes of damping-off in different plants, but the principal one affecting corn in Arizona is a species of *Rhizoctonia*.

Symptoms

A typical symptom of damping-off is the sudden toppling over of the young plant. Upon examination the stem at or near the surface of the ground shows a brown discoloration and shrunken condition where the tender tissues have been killed by the invading fungus. In the case of early infection of the germinating seed the seedling may be killed before it emerges from the soil.

Control

Since cool weather and abundant moisture favor the development of the disease, later planting may be advisable in order to escape cold spring days. Plants which are slightly infected may recover with the advent of hot, dry weather. The number of grains planted per hill may be increased in order to allow for the death of some seedlings; the soil should be kept as dry as consistent with good growth during the seedling stage. Frequent cultivation results in drying and aerating the soil, which are also favorable to the crop.

Rust *(Puccinia sorghi)*

In the Corn Belt the corn plant is subject to a rust similar to that on wheat and other small grains. The disease has been reported in Arizona only from Cochise County. Long periods of hot, dry weather and the absence of Oxalis, the alternate host

[31] Stevens, F. L.—Diseases of economic plants. New York. 1923.

plant of the corn-rust fungus, make conditions unfavorable for the development of the rust.

Symptoms

The small, brown pustules of spores on the leaves are easy to recognize (Fig. 19). Sweet corn and flint varieties are more susceptible than dent varieties.[32]

Fig. 19.—Many small, rust-colored pustules on the leaf is a symptom of corn rust. x 1.

[32] Weber, G. F.—Studies in corn rust—Phytopathology 12: 89-97. 1922

COTTON

Alternaria Leaf-Spot *(Alternaria sp.)*

Alternaria leaf-spot is increasing in importance in Arizona. The disease was present in all cotton districts a few years after cotton growing started in the State.[33] At that time the leaf-spot appeared in late summer or early fall and was regarded by farmers as beneficial rather than injurious, for the infection and light defoliation were believed to hasten the maturity of the bolls. Later the disease came into cotton fields in mid-summer or earlier and, in some cases, caused extensive defoliation and boll-shedding, so that the crop was reduced by 50 per cent or more. Attacks were usually more severe in weed-bordered and infested fields. Although sometimes associated with the true rust of cotton caused by *Aecidium gossypii*, the leaf-spot has also been bad in districts in which the rust has not appeared. The disease can and does cause extensive defoliation in fields which apparently have not been injured by other organisms.

Symptoms

The spots (Fig. 20X) at first are very small, approximately round, red areas. As they increase in size the center becomes straw color to gray with a red to purplish margin. Similar spots may appear on the petioles of leaves, the pedicels of bolls as well as on the bolls, and even on the tender stems. On the leaves and bolls the spots may become irregular in outline (Fig. 20G), almost black, and show concentric rings. On petioles, pedicels and stems they become elongated. As a result of attack there is always more or less leaf-fall. Bolls may be blighted, dry out and remain attached to the plant or, if the pedicels are attacked, they may be shed.

Control

No practical means of control is known. The eradication of weeds which help to prevent proper aeration of the cotton field and possibly accumulate a coating of the abundant spores of the causal fungus, is advisable.

Angular Leaf-Spot, Black-Arm, Bacterial Boll Rot *(Phytomonas malvacera)*

Angular leaf-spot, black-arm, and bacterial boll rot of cotton are all caused by the same bacterium, *Phytomonas malvacera*, and are different phases of the same disease. Losses from the disease have been recorded in most cotton-growing countries of the world. Varieties of long-staple cotton, such as Pima-Egyptian and Sea Island, are most susceptible, but short-staple cottons are also attacked. In Arizona the disease has been worst on the

[33] Brown, J. G. and Gibson, Frederick—Brief summary of plant disease determinations—Ariz. Agr. Exp. Sta. Ann. Rept. 33: 244. 1922.

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Pima-Egyptian variety, but within the past five years it has been increasing in other varieties, especially in the smaller eastern districts of the State. Besides cultivated cotton two other plants are susceptible to the angular leaf-spot bacterium, namely, Ari-

Fig. 20.—Parts of three leaves of Pima-Egyptian cotton with different stages of Alternaria leaf-spot. E. Very young spots at "x", older spots with red margins and light centers, "y". F. Some spots are merely larger than those shown at "y" and have red margins with light centers, other spots are entirely covered with almost black spores, some are beginning to show the characteristic target rings. G. Several spots have run together and the target rings are marked.

zona wild cotton *(Thurberia thespesioides)* [1] and the kapok tree *(Eriodendron anfractuosum)* [2] which grows on the Pacific Coast of tropical America.

Symptoms

1. *On the seedling.*

Round, water-soaked spots appear on one or both seed leaves (cotyledons). The spots may enlarge and run together to make a large lesion which may include much of the surface. Sometimes the cotyledon is cracked and torn in freeing itself from the seed coats; then there are water-soaked spots and streaks on the edges of the injuries. Very small, water-soaked lesions often occur on the margin of the cotyledons. The lesions here described are shown in Fig. 21. The water-soaked spots may show a light yellow bacterial ooze on the surface; as they become older and dry they turn black. The seedling withdraws food materials from the seed leaves or cotyledons which finally collapse against the stem. Condensed moisture runs down the cotyledons onto the stem, carries the germ of angular leaf-spot with it, and starts the black-arm stage. (Fig. 21D).

2. *On the stem.*

Black-arm lesions on the stem are water-soaked at first but later they become reddish to brownish black, sometimes deep black. They may be oblong, running up and down the stem, or they may run around (girdle) the stem. Cotton plants often outgrow the disease; in other cases the black-arm stage so weakens the plants that they are easily broken by wind and contact with farm implements used in cultivation. In Arizona whole fields occasionally consist of sick, sprawling plants too weak to stand erect and consequently are plowed under.

3. *On the leaf.*

Infected spots on the leaves are mostly small, water-soaked areas which are angled (Fig. 22) because they are limited by the veinlets. Another type of spot lies along large or somewhat smaller veins and is likewise water-soaked in appearance at first. The spots in the water-soaked stage become easily visible when the infected leaf is held toward the light. Bacterial ooze may show on the spots on the leaf as well as on stems and bolls. Finally the spots darken in color. They cause loss by defoliating the plant.

4. *On the boll.*

Bacterial spots on the boll are commonly round, water-soaked areas which are small at first but may spread over a

[1] Brown, J. G. and Gibson, Frederick—A new host for Bacterium malvacearum—Phytopathology 13: 455-457. October, 1923.

[2] Palm, B. T.—Eriodendron as host of Bacterium malvacearum—Phytopathology 22: 867-868. October, 1932.

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Fig. 21.—Cotton angular leaf-spot. A,B,C and D illustrate how the permanent black-arm phase on the stem often results from infected lint. A Lint holds cap of soil on seed-leaves (cotyledons) and young spots, "l," of disease start; B Cap of soil and seed-coats is finally thrown off, but seed leaves are injured and badly infected at "s." C Angular leaf-spot lesions, "i," have become numerous. E. Seedling is much older, a diseased seed-leaf has collapsed against the stem; moisture running downward has carried the bacterium of angular leaf-spot from seed-leaf to stem and has started the black-arm phase of the disease, "b." F Angular leaf-spot lesions, "s," on a bract of the cotton flower.

Fig. 22.—Angular leaf-spot of cotton. Symptoms on the leaf. Two types of lesions are present: the small, angular spots and the elongated spots along the larger vein to the left.

large part of the carpels or sections (Fig. 23). The bacterium at the same time makes its way inward and causes staining and decay of the lint. We have never found it inside the seeds but have cultured it many times from the lint, even from two-year-old seed. The spots may girdle the stem of the boll and cause drying and shedding. All spots turn dark with age, when they are brownish black or black unless other organisms enter; then they may be pink, sooty black, or rusty in color. Similar water-soaked spots may occur on the bracts or squares, but the common type of spot here is a narrowly oblong one (Fig. 21E). Sources of loss from the angular leaf-spot disease on the bolls are the drying of young bolls which may never mature; boll-shedding; premature opening of the boll, and staining and decay of the lint.

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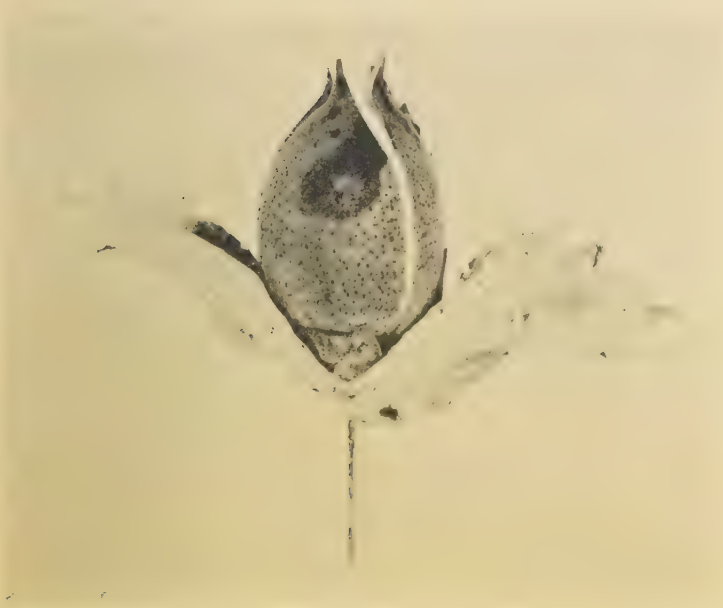

Fig. 23.—Cotton angular leaf-spot. The large bacterial lesion on the carpel of the boll permits drying. Since the loss of water is faster on the outside of the carpel than on the inside, contraction of the carpel is greater on the outside. The pull causes premature opening of the boll.

Spreading of Angular Leaf-Spot in the Field

In Arizona, at least, angular leaf-spot always appears to come into a field of cotton on the seed. Once established the disease may be spread by irrigation water from basal stem lesions to the stems of healthy young plants; by the contact of diseased with healthy plants during winds; and by the spattering action of raindrops in a shower.[34] Insects are unimportant in spreading the disease, although the cotton dauber[35] may occasionally transfer the angular leaf-spot bacterium to the boll.

Control

Angular leaf-spot is perfectly controlled by the use of seed which has been delinted with concentrated sulphuric acid.[36] Cotton seed treated in this way usually sprouts quicker than gin-

[34] Faulwetter, R. C.—Dissemination of angular leaf-spot of cotton—Jour. Agr. Res. 4: 457-475. March 19, 1917.

[35] McGregor, E. A.—Lygus elisus: a pest of cotton regions in Arizona and California—U. S. D. A. Tech. Bul. 4. July, 1927.

[36] Brown, J. G. and Gibson, Frederick—A machine for treating cotton seed with sulphuric acid—Ariz. Agr. Exp. Sta. Bul. 105. May, 1925.

run seed; gives a more uniform, healthier stand, and is easier to handle since it runs through the planter like peas and beans.

Boll Rots *(Aspergillus niger; Rhizopus nigricans; Phytomonas malvacera)*

The commonest decays of cotton bolls in the southwestern states are caused by the fungi, *Aspergillus niger* and *Rhizopus nigricans*, and by the bacterium, *Phytomonas malvacera*. The first two boll rots were found by Shapovalov[39] to be most prevalent in southern California, although they were also found in the San Joaquin Valley, in Mexico south of the Imperial Valley, and in Arizona. Data from Arizona show that the fungous diseases are most common in Yuma County where losses of 20 per cent have occurred, and they are found to a greater or less extent in all cotton-growing districts of the State. Bacterial boll rot (Page 146) occurs in the Salt River Valley, Marana, Safford, and Duncan districts.

Symptoms

The boll rot caused by *Aspergillus niger* (Fig. 24), the commoner of the two fungi, begins as a soft, pinkish spot on the side or base of the green boll. As the lesion grows larger the characteristic pink color changes to brown in the center, the margin remaining pink. The infected areas inside the boll are pink to purplish with red-brown shades. Spore production of the fungus begins early and the spore masses change from white to light gray, then rapidly to a sooty black. The fungus destroys the lint and seeds as well as the capsule. If all the locks are infected the boll dries up without opening, but locks that are not infected open normally.

The decay of the boll caused by *Rhizopus nigricans* (Fig. 24) is distinct in all its stages of development. The pink coloration of the Aspergillus rot is entirely lacking; instead, the olive-green discoloration caused by Rhizopus persists until the decayed parts dry up, although the color deepens with age. Brown or reddish shades are absent in early stages of infection. The discoloration inside the boll is not uniform but varies from steel gray to very light purple and the seeds sometimes show shades of pink and yellow. The spore masses are a dark gray or blue-gray which is distinct from the sooty black of Aspergillus.

Both fungi causing boll-rot are generally, if not exclusively, wound parasites, that is, they rarely if ever gain entrance through uninjured tissues. Infection often occurs through injuries made by the boll worm or other chewing insect. The fungi may break through the boll at a spot other than the place of infection. External lesions appear in from three to eight days after infection.

[39] Shapovalov, M.—The two most common decays of cotton bolls in the southwestern states—Jour. Agr. Res. 35: 307-312. 1927.

Both fungi also attack small squares, pedicels, and bracts, and Shapovalov[89] finds them forming stem lesions on cotton seedlings, although Rhizoctonia is the principal cause of soreshin.

Fig. 24.—Boll rots of cotton. Top row: Rhizopus rot; bottom row, Aspergillus rot. In both cases the lint is matted, stained and worthless. x 0.5.

The bacterium, *Phytomonas malvacera*, can enter the boll and neighboring parts of the cotton plant through "breathing pores" or stomata; it is also carried and communicated to the boll by insects, particularly by the cotton stainer. Infection with the bacterial parasite is often followed by the entrance of the fungi previously mentioned. For a description of the symptoms of bacterial boll rot and measures for its control see pages 146, 148-150.

Control

Since infection with the fungi which cause boll rots apparently depends upon insect injuries, the control measures are necessarily

directed against insect pests which is the work of the entomologist rather than the plant pathologist. The bacterial boll rot is perfectly controlled through the use of sulphuric acid-delinted seed.

Crazy-Top (Physiological)

The disease of cotton known as crazy-top is serious in Maricopa and Pinal Counties where it sometimes affects an estimated 50 per cent of the fields. Both Pima and Upland varieties are susceptible, although the disease has been found to be more severe in the latter.[40]

Symptoms

The name "crazy-top" comes from the peculiar growth of affected plants. Early normal growth suddenly changes to abnormal growth. Thus the upper joints of a cotton plant may exhibit more or less upright fruiting branches in contrast to the normal horizontal branches on the lower part of the same stem. The wood cylinders of branches may be divided although the bark remains entire. Affected plants may be dwarfed by the failure of the internodes to elongate normally and by the restricted growth of the leaves. Flower buds may abort at any stage in their development; frequently the whole plant remains sterile or, at best, makes only a few bolls. Pima cotton affected with crazy-top is more susceptible to angular leaf-spot (Pages 144-150) than normal plants of the same variety, which may cause extensive defoliation.[41]

Cause

Unfavorable conditions of the soil are suggested as the cause of crazy-top.[41] Among the causes are mentioned cemented or otherwise non-porous soils, steep grade of land which hinders deep penetration of water, and soils impoverished by continuous cropping to cotton.

Control

Rotation of cotton with alfalfa and deeper irrigation with more constant available moisture are practicable means for the control of crazy top.

Root Knot *(Caconema radicicola)*

Root knot of cotton and several hundred other plants is caused by a small round worm which is also called eelworm and nematode. The worm lives in the soil in plant roots. When it enters the tender part of a root, the nematode stimulates local growth

[40] Cook, O. F.—Acromania or "crazy-top," a growth disorder of cotton—Jour. Agr. Res. 28:: 803-827. May 24, 1924.

[41] King, C. J. and Loomis, H. F.—Factors influencing the severity of the crazy-top disorder of cotton—U. S. D. A. Dept. Bul. 1484. June, 1927.

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and the result is a lump or knot which gives the name "root knot" to the disease. The knots may be so numerous as to give the root a resemblance to a string of beads.

Root knot is widespread in the cotton states. Not only does the disease directly reduce the yield, but it also aids other para-

Fig. 25.—Crazy-top of Hartsville cotton. A. Small bolls produced at the end of the season; B. Normal late-season bolls of healthy plants in the same field. (After O. F. Cook.)

sites, such as Texas root-rot fungus, to gain entrance. Root knot usually is worse in the lighter soils, although it also occurs in heavy soils.

Symptoms

Cotton plants attacked by root knot are yellowed and dwarfed eventually, although they may appear almost normal in the early stages of the disease. When suspected plants are pulled up, the knots are so conspicuous that identification is easy. The galls vary in size from those barely visible to lumps one-half inch or more in diameter; they interfere with the movement of food and water in the cotton plant, thus resulting in stunting and wilting.

Cause

The cause of root knot is a small worm which is about one thirty-second inch long at the time the roots are entered. The young male worm matures in three to four weeks, seeks and fertilizes the female, then dies. The female worm becomes pear-shaped and begins to lay eggs at the rate of ten to fifteen per day; she may deposit sixty to five hundred eggs. The eggs may remain dormant for a time or they may hatch in two to six days, depending upon conditions; thus it is possible for a generation, egg to egg, to be produced in about a month. Young worms inside the root knot are set free by the decay of the root.

Spread

The worm which causes root knot may be carried in soil, by irrigation water, on tools and implements, on the feet of men and animals, and in the roots of plants. Rooted plants obtained from any nursery or from farmers are to be suspected. The roots of such plants should be carefully examined before they are reset, even though a plant inspector has already gone over them. Plants having knots in the roots should be destroyed.

Control

The cheapest control for root knot is continual watchfulness to prevent its introduction. In Arizona the disease is most frequently brought to farms on nursery stock. Even while this bulletin is in course of preparation several persons have brought to us trees sold to them by nurserymen as healthy which are badly diseased with root knot. Once the nematodes become established in the soil, eradication is next to impossible. Every rooted plant which is brought to the farm should be examined for lumps in the roots and promptly burned when found infected.

Where nematode worms are already present in the soil and are seriously attacking cotton their numbers should be reduced by growing root-knot resistant crops such as corn; Iron, Brabham and Monetta cowpeas; sorghums; peanuts; and bush velvet beans. The last named is the most resistant and we have successfully

grown the crop at Tucson. When weeds are kept out the bush velvet bean will almost starve out the common nematode in two seasons.

Thorough drying of infested soil kills the root-knot nematode and this method of control is well adapted to our climate. Irrigation should be entirely suspended while the soil is dry-worked as frequently as possible for a season. Other methods which have been tried are the use of chemicals, fertilizers, and flooding, all of them more or less unsatisfactory for cotton fields because of the cost or for other reasons.

Soreshin *(Rhizoctonia solani; Corticium vagum)*

Soreshin is a disease of seedling cotton plants common wherever cotton is grown. It is prevalent in Arizona. In years when it is severe soreshin is the cause for the replanting of thousands of acres of cotton where the stand has been destroyed. The cost of replanting does not accurately measure the loss from this disease because the later crop often gives a much lower yield.

Symptoms

The usual type of invasion, which is called soreshin or rhizoctoniose, is characterized by a reddish-brown discoloration of the tissues at and just below the soil line (Fig. 26). Infection very often appears only on one side of the stem in the form of an ulcer which gradually deepens until the vascular system is reached. At this stage the life of the plant is endangered, but plants often recover when the weather changes from cool and wet, which is favorable to the development of the disease, to hot and dry, which is unfavorable to the disease. Infection may progress slowly or rapidly, depending upon temperature and moisture.

Atkinson[42] describes another type of soreshin in which the tissues of the cotton seedling undergo a soft rot which progresses very rapidly with very little discoloration in the early stages of the disease.

Cause

The causal fungus, *Rhizoctonia solani (Corticium vagum)*, is widely scattered and occurs on a large number of hosts. Peltier[43] in 1916 listed 165 species of plants known to be susceptible to rhizoctoniose in the United States, including most vegetable and field crops, herbaceous plants, flowers, and many weeds. In Arizona strawberries, potatoes, beans, sweet peas, garden and field peas and lettuce have been severely attacked. Since infection has appeared on virgin land during the first year of cultivation under circumstances in which Rhizoctonia could not have been introduced, it appears that certain soils are naturally in-

[42] Atkinson, G. F. Quoted by Peltier; see reference number 43.

[43] Peltier, G. L.—Parasitic Rhizoctonias in America—Ill. Agr. Exp. Sta. Bul. 189. 1916.

fected with the fungus. Rhizoctonia is abundant in some cultivated fields where it may live either on dead organic matter in the soil or on weeds and other plants.

Fig. 26.—Soreshin of cotton. A. Seedlings to show lesions on stem and root near soil line; lateral roots are dying. B. Somewhat magnified photograph of soreshin on cotton seedling.

No evidence of the specialization of strains of *Rhizoctonia solani*, such as occurs in stem rust of wheat, is found by Peltier.[43] All strains of the fungus will attack the same host plants, but the virulence is quite variable as is also the degree of resistance of the host plants. Infection is most severe at low soil temperatures and decreases as the soil becomes warmer until it becomes negligible at approximately 80° F.[44]

Control

Under conditions in Arizona low temperatures with an excess of moisture in the surface layers of soil are the conditions most

[43] Walker, M. N.—Cotton diseases in Florida.—Fla. Agr. Exp. Sta. Bul. 214. 1930.

favorable to soreshin. Early planting is liable to expose cotton to these unfavorable conditions. Planted later when the soil is warmer cotton seed germinates more rapidly and the crop usually escapes the disease.

Control of irrigation is important. Filling the soil with water to a depth of 3 or 4 feet by generous irrigation and planting when the surface layers are dry enough to work properly will make unnecessary further irrigation for a month or six weeks after planting. Irrigating in cool weather a field which shows considerable soreshin will only make matters worse and will often make necessary the replanting of the entire field. A light cultivation to dry the surface of the soil may be advisable.

Losses from soreshin are decreased by planting sulphuric-acid delinted seed which germinates quickly so that the plant is soon past the susceptible seedling stage. According to Rosen,[1] a 0.25 per cent solution of Uspulun sprayed on young cotton plants also controls the disease, but the extra cost for disinfectant and labor probably would make spraying impractical.

Southwestern Rust (*Puccinia hibisciata; Aecidium gossypii*)

Cotton in Arizona, especially in the Santa Cruz Valley, is subject to attacks of a disease caused by the cluster-cup stage of a rust fungus. The disease may be so mild that it remains almost unnoticed for several years, then may suddenly appear in severe and epidemic form. Again it may cause considerable loss in a district for several successive years. Heavy losses occurred in 1922 and as high as 75 per cent of the yield in large fields in 1930. One field, which was estimated to make over a bale of lint per acre before the rust appeared, was so thoroughly defoliated that it yielded only one-fourth bale of inferior lint per acre.

Symptoms

Cotton rust causes roughly circular spots from three-sixteenths to one-half inch in diameter on the leaves (Fig. 27) and other green parts. From above the spots are dark, reddish purple; on the lower side they are orange yellow. After a few days the center of the spots, on the lower side, breaks out with tiny pustules which emit a yellow powder consisting of the small spores of the rust fungus. Mild infection only partly destroys the efficiency of the leaves, but severe infection causes partial or total defoliation.

Cause

Cotton rust in the Southwest is caused by the fungus, *Puccinia hibisciata*, also called *Aecidium gossypii*. It has been reported

[1] Rosen, H. R.—The control of damping off of cotton seedlings by the use of Uspulun—Science 60: 384. Oct. 24, 1924.

from Arizona,[16] Texas,[17] and California.[18] The occurrence of the rust appears to be dependent upon summer rains sufficient to create periods of high humidity during which infection occurs. The cotton-rust fungus has a life history similar to that of the wheat-rust fungus (Pages 201-204) in that both rusts alternate between a wild and a cultivated host plant. In the case of southwestern rust the wild hosts are believed to be species of wild grasses *(Muhlenbergia* and *Sporobolus)* which, in turn, supply the source of infection for cotton the following year. It has been noticed that rust is more severe on cotton planted on land adjoining uncultivated desert areas than elsewhere, which strengthens the belief that wild grasses serve as a source of infection for cotton.

Fig. 27.—Southwestern rust on upper surface, A, and lower surface, B, of cotton leaf.

Control

Satisfactory control measures are difficult to work out until more is known about the disease, the life history of the rust fungus, and the wild hosts. The supposed source of infection on wild grasses could not be completely eliminated, even by the de-

[16] Brown, J. G. and Gibson, Frederick—Brief summary of plant disease determinations—Ariz. Agr. Exp. Sta. Ann. Rept. 34: 501. 1923.

[17] Taubenhaus, J. J.—On a sudden outbreak of cotton rust in Texas—Science 46: 267-269. 1917.

[18] Brandegee, K.—Aecidium gossypii on leaves of cotton, San Jose del Cabo, Lower California—Erythea 5: 6. 1897.

struction of the grasses in cotton districts, because the rust spores may be carried for miles on currents of air. The cotton plants might be protected from infection by spraying or dusting just before the period of infection if this period were accurately known. In fact dusting experiments were carried on in 1932 as soon as the first rust spots appeared, but the year was not a bad rust year; therefore the value of dust as a preventive of rust could not be ascertained. Little is known about the comparative resistance of cotton varieties to rust. In 1922 the Durango variety at Postvale remained free from rust, although Acala and Pima-Egyptian varieties in adjacent fields were badly attacked.

Other Cotton Rusts

Southwestern cotton rust should not be confused with the "cotton-rust" disease of the Gulf States, which is a nutritional disturbance causing irregular brown spots on the leaves and which occurs rather extensively on the poorer soils. There is also another true rust of cotton caused by *Cerotelium gossypii (Uredo gossypii)* which forms inconspicuous brown pustules on the leaves. This rust is prevalent in southern Florida, Cuba, and Porto Rico but is not found in the Southwest.

Texas Root Rot *(Phymatotrichum omnivorum)*

Texas root rot is the most prevalent and destructive disease of cotton in most localities in Arizona. Apparently cotton plants under one month of age are not attacked; the disease usually appears in late June or July when it causes more or less circular spots of dead plants. The spots increase in size until just before killing frost when the maximum effect of the disease is visible. Plants killed late in the season often open some bolls, but the lint is poor in quality and reduces the grade of cotton with which it is mixed. Losses in yield up to 80 per cent or greater have been recorded.

Symptoms

The first visible symptom of root rot is a wilting of the foliage during the afternoon when the leaves of infected plants may feel "feverish" to touch. Diseased plants may recover over night, but they soon go into a permanent wilt and suddenly die. The root system is extensively decayed and the cortex (bark) of the roots readily sloughs off. On the surface of roots which have been carefully removed from the soil usually there can be seen slender strands of the root-rot fungus which look like small, fuzzy, tan to light brown pieces of string (Fig. 28). Under the microscope the strands show very distinctive, cross-shaped branches of the fungus. Spore mats and sclerotia, described under root rot of alfalfa (Pages 123-125), are also found in fields of cotton and other host plants.

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Control

Rotations with resistant crops have been the most satisfactory method of control for root rot in cotton and other field crops. In such rotations the following may be used: small grains such as wheat, barley, oats and rye; corn, grain sorghums, grasses, cantaloupes, winter lettuce, asparagus and onions. In order to make rotations effective susceptible weeds must be kept out. On account of the persistence of the fungus in the form of resting bodies (sclerotia) and in dead roots deep in the soil, it is impossible to predict the length of rotations necessary to eradicate root rot. In some cases two years without susceptible crops and weeds will eradicate or much reduce root rot; in other cases even three or four years of rotations with non-susceptible crops may not eradicate the disease.

Fig. 28.—Strands of the Texas root-rot fungus on root of dying cotton plant. x 3.

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Barriers

Although they are too expensive for general use, barriers can be constructed to restrict the spread of the root-rot fungus from small infected areas. To be effective barriers must check both plant roots and fungus; they must be at least $3\frac{1}{2}$ to 4 feet deep. Barriers are made by digging a trench at a safe distance in advance of the fungus (8 to 10 feet beyond the dead plants in a root-rot spot) and refilling the trench with a layer of soil prepared to stop the fungus and roots. Among the materials found useful to mix with the soil are copper sulphate, sulphur, sulphuric acid, and heavy oil used in surfacing roads. The location of barriers should be marked so that they may not be destroyed by plowing and cultivating the crop.

Another type of barrier consisting of immune plants has been suggested.[49] It has been found that cotton roots will not extend beneath adjoining rows of sorghum; four to twelve rows of the latter should be planted around the root-rot spots to be checked.

Soil Treatment

Very heavy, repeated applications of organic matter will reduce to a minimum losses from root rot, although they will not eradicate the disease. Heavy applications of ammonium sulphate probably will give as good or better results (Pages 219-220). Disinfection of the soil (Pages 218-221) is possible where it is desired to eradicate small infections in order to prevent the spread of the fungus into valuable land. Chemical treatments (Page 219) are too expensive where more than a few square rods of soil are infected.

Waxahachie Wilt *(Fusarium sp.)*

In 1921 a disease of cotton appeared near St. David, Arizona, which was diagnosed in the field as wilt caused by *Fusarium vasinfectum*.[50] Cultures of the fungus were made from surface-sterilized stems and roots which gave almost pure growths of Fusarium. The cultures were sent to an eastern specialist for study and comparison with other species of Fusarium. Although acknowledgment was made of the arrival of the cultures, it was afterward claimed that the package was lost in some way. Since then Taubenhaus, Ezekiel and Rea[51] have described a wilt of cotton in Texas which is probably the same disease found at St. David: *Fusarium vasinfectum* is said not to attack cotton in

[49] Taubenhaus, J. J. and Ezekiel, Walter N.—Cotton root-rot and its control—Texas Agr. Exp. Sta. Bul. 423. April, 1931.

[50] King, C. J. and Loomis, H. F.—Cotton root-rot investigations in Arizona—Jour. Agr. Res. 39: 199-221. 1929.
Brown, J. G. and Gibson, Frederick.—Miscellaneous studies. Ariz. Agr. Exp. Sta. Ann. Rept. 32: 611. 1921.

[51] Taubenhaus, J. J., Ezekiel, W. N., and Rea, H. E.—A new cotton wilt. Phytopathology 19: 171-173. 1929.

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alkaline soils; the wilts found in Arizona and Texas occurred on soil with an alkaline reaction.

Symptoms

In the field the so-called new or Waxahachie wilt cannot be distinguished from the well-known southern Fusarium wilt. Cotton growers in Arizona would almost invariably mistake either disease for Texas root rot. However, the wilting of the infected plant is sometimes more sudden than in the case of root rot. Examination of the root system at once shows a difference, since the root rot first causes decay and loosening of the bark followed by destruction of the root. No discoloration of the wood in the stem appears in root rot, but in the new wilt the central wood of the stem becomes browned or blackened (Fig. 29). Stunting is another symptom which may accompany the wilt disease. Unlike the fungus of the southern cotton wilt *(Fusarium vasinfectum)*. that of the new wilt can live in alkaline soil.

Recently Ezekiel and Taubenhaus[33] have published results on variety tests with the old Fusarium wilt and the new or Waxahacie wilt. Varieties of cotton which are resistant to *Fusarium vasinfectum* are not necessarily resistant to the Fusarium which causes the new wilt; likewise varieties susceptible to the former were not all equally susceptible to the latter. The authors conclude that the two wilts are distinct.

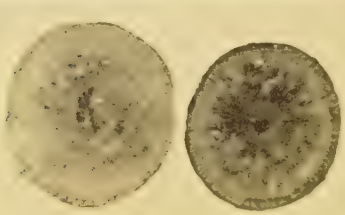

Fig. 29.—Cotton stem with Waxahachie wilt cut across to show internal discoloration of the wood.

Control

Unless the new Fusarium wilt reappears and increases in extent, the subject of control is of minor importance. Varieties of cotton which are resistant to the southern Fusarium wilt are well known. It is probable that commercial varieties resistant to the new wilt will be developed. Farmers are requested to send to us any wilted cotton plants which show browned or blackened wood when the stems are split.

FLAX

Anthracnose *(Colletotrichum lini)*

Anthracnose or fungous canker of flax is found in Europe and Asia as well as in America. At times it is destructive. Since the

[33] Ezekiel, Walter N. and Taubenhaus, J. J.—Variety tests in the differentiation of two cotton wilts—Phytopathology 24: 292-295. March, 1934.

fungus may be carried on flax seed,[54] it may be brought into Arizona at any time.

Symptoms

Seedlings attacked by anthracnose damp off (Fig. 30) and mature plants are weakened and browned. The seeds of sick plants become shrivelled. Symptoms resemble those of heat canker and wilt. Suspected plants should be sent to the Agricultural Experiment Station for study.

Fig. 30.—Young flax plants with anthracnose lesions at soil line; healthy plant at right (after Reddy and Brentzel).

Control

See flax wilt, page 168.

Heat Canker (Physiological)

This disease is common where flax is grown in semi-arid regions. It affects plants up to 5 inches in height. Those less than 3 inches high are killed quickly; plants between 3 and 5 inches high may remain alive for a much longer time.

[54] Bolley, H. L. and Manns, T. F. –Fungi of flaxseed and flax-sick soil– N. Dak. Agr. Exp. Sta. Tech. Bul. 259. June, 1932.

FLAX

Symptoms

The outside of the stem is killed at the soil line (Fig. 31A). Small plants wither and dry; larger plants fall to the ground and the stem breaks where the injury occurs. On the latter the stem is often swollen just above the injury, or both above and below it (Fig. 31B).

Fig. 31.—Flax. A. Two young plants at left have heat canker; healthy plant at right. B. Older plants have callus at girdle and broken stems caused by heat canker. This disease is often confused with anthracnose.

Cause

Injury results during and immediately after very hot days. The heated surface-soil in contact with the tender stem causes the disease.

Control

Thick seeding, early sowing, and drilling rows north and south instead of east and west are suggested preventive measures.[55] The disease has not yet been observed in Arizona.

Pasmo (*Phlyctaena linicola*)

The pasmo disease has not appeared in Arizona but it is included here because it may easily be introduced in seed and early identification may aid in combating the disease. Pasmo has been

[55] Reddy, C. S. and Brentzel, W. E.—Investigations of heat canker of flax—U. S. D. A. Dept. Bul. 1120. Oct., 1922.

found in the Dakotas, Minnesota, and Michigan where it is believed to have been introduced in imported seed.

Fig. 32.—Pasmo disease of flax (after Brentzel).

Symptoms

Although seedlings may be attacked, the disease usually is first noticed just before harvest time. Then the field shows spots

of brown plants which are not sharply delimited with respect to the healthy stand, but consist of slightly affected marginal plants about severely attacked central plants. Small, elongated brown lesions form on the lower part of the stem and extend around and upward, giving to the plant a mottled green and brown appearance (Fig. 32). On the leaves spots develop which are greenish yellow to dark brown; the leaves finally wither and fall. Lesions first show on the seed-leaves of seedlings, afterward on the true leaves, but rarely on the seedling stems.

Control

Stubble and infected straw in the field should be burned or plowed under immediately after harvest. Flax should not be sowed in a field in which pasmo has appeared the previous year. Since the spores of the pasmo parasite may be carried on seed, disinfection should be practiced. Argentine varieties are most susceptible to the disease.[56]

Wilt *(Fusarium lini)*

Flax is new to Arizona and the acreage is small. At this time when the crop is being introduced marked attention should be paid to diseases, especially those which are seed-borne. Wilt is such a disease. Once it becomes established in the soil, eradication is difficult and costly if not impossible. According to authorities on flax wilt,[57] there is "no evidence that the disease can be controlled by any type of crop rotation now known." The disease is world-wide in its distribution, therefore the importation of infected seed is to be expected. We believe that *all flax seed brought into Arizona should be disinfected.*

Symptoms

Although the greatest damage resulting from wilt occurs in the seedling stage, the disease can attack flax at any time during its growth. Seedlings are completely destroyed; indeed they may be killed before they reach the surface of the soil. After emergence infected seedlings wilt suddenly and dry up or rot. Older infected plants become weak, wilt at the top, yellow, and die (Fig. 33). Sometimes wilted and yellowed leaves show only on one side of the plant. The roots of sick plants are killed, then become ash gray. As in the case of Texas root rot plants attacked by Fusarium wilt are easily pulled up; another similarity to root rot is the roundish shape of infected spots in flax fields.

Cause

The cause of flax wilt is *Fusarium lini*, a fungus which can live in the soil on dead organic matter for years. It may become very abundant as shown by Bolley and Manns[57] who obtained 600 to

[56] Brentzel, W. E.—The pasmo disease of flax—Jour. Agr. Res. 32: 25-37. 1926.

[57] Bolley, H. L. and Manns, T. F.—Fungi of flaxseed and of flax-sick soil—N. D. Agr. Exp. Sta. Tech. Bul.—259. 1932.

15,000 colonies in cultures per gram (1/28 ounce) of soil. The fungus thrives best at soil temperatures between 79 deg. F. and 82.5 deg. F., but it can grow at 50 deg. F. and at temperatures as high as 98.5 deg. F.[58] It enters the flax plant through the root hairs, penetrates to the wood strands, grows upward through root and stem, and chokes and poisons the plant. Infection finally reaches the pods where the fungus sticks to the surface of the seeds and enters their coats. It may be expected to be deep-seated in light, shrivelled seed. Here it remains dormant until the seed is planted; then it attacks the seedling and spreads through the soil. Abundant spores are produced.

Fig. 33.—Flax wilt in young plants. The first stages of wilt suggest effect of water shortage. x 0.5.

[58] Tisdale, W. H.—Relation of temperature to the growth and infecting power of Fusarium lini. Phytopathology 7: 356-360. 1917.

FLAX

Control

Seed treatment and the use of resistant varieties afford means for avoiding loss from flax wilt. Light, shrunken, discolored seed is almost sure to be infected and disease is also carried on such debris as small pieces of straw, chaff, and soil. Only bright colored seed should be used for sowing, and the seed should be carefully cleaned and graded before it is treated.

The solution for treating flax seed is 1 pound of 40 per cent formaldehyde in 40 gallons of water. The disinfectant is applied in a fine mist with a pressure sprayer while the seed is rapidly shovelled or raked on a canvas or other clean surface. One-half to two-thirds gallon of disinfectant is required per bushel of seed. When the seed is thoroughly wetted it is covered with a canvas for two to three hours, but during the first hour the seed should be shovelled or raked at least twice.

Flax should be grown in a given field not oftener than once within a period of five years. Frequent change of seed is a bad practice, for new seed may be diseased; therefore farmers are advised to grow their own seed. Where wilt occurs, seed should be saved from resistant plants and, after treatment, should be increased in a seed plot.

JOHNSON GRASS

Smut *(Sphacelotheca sorghi)*

Although Johnson grass is regarded as a very troublesome weed, hay from it has sold at a premium more than once in Arizona. The plant is very common and widespread within the State. Every year we receive a few specimens of smutted heads (Fig. 34) with requests for a diagnosis. The smut also occurs on sorghum (Pages 186-188) and is described under that heading.

OATS

Oats are grown in Arizona for hay and grain, but the acreage is small. The crop for grain is limited chiefly to the central and northern parts of the State. Diseases of oats which are important in Arizona are covered smut, loose smut, and rusts.

Covered Smut *(Ustilago levis)* and Loose Smut *(Ustilago avenae)*

Although covered smut and loose smut are caused by two different fungi, they may be described together for practical purposes. Heads infected with covered smut usually appear a little later than those infected with loose smut, the former with or shortly after the normal heads; the latter somewhat before or with the normal heads. The two smuts may be distinguished by their behavior: covered-smut spores remain in masses in the head until the grain is threshed; loose-smut spores soon blow away, leaving only the bare stalk of the head. Spores of both

OATS

smuts are carried on the grain[50] and cause infection in the new crop.

Fig. 34. Johnson grass. A Healthy head. B Smutted head. The smut fungus destroys the seed. x 1.

[50] Reed, George M.; Griffiths, Marion C.; Briggs, Fred N. Varietal susceptibility of oats to loose and covered smuts. U. S. D. A. Dept. Bul. 1275. 1925.

OATS

Fig. 35.—Smuts of oats: A. Covered smut; B. Loose smut.

Evidence that there are different strains of both covered- and loose-smut fungi has been accumulating in pathological laboratories. Furthermore, new kinds of oat smut are probably appearing. One way in which new smut fungi arise has been shown by Holton[60] who found that *Ustilago levis* (the covered-smut fungus) may hybridize with *Ustilago avenae* (the loose-smut fungus). Crossings between the two fungi, occuring in nature, may result in new smut fungi which can attack varieties of oats resistant to older forms of smut fungi; in other words, oats which have never been susceptible to smuts may later become smutted because they are attacked by new kinds of smut fungi to which they are not resistant.

Control

The possibility of the origin of new smut fungi by hybridization or in other ways detracts from the value of so-called resistant oats and emphasizes the importance of seed treatment. Fortunately there are available several cheap, effective treatments for the control of oat smuts (Pages 209, 217).

For the twenty-one chemical dusts and formaldehyde dip tried by Tapke[61] on twenty lots of naturally infected oats, the following observations are recorded:

[60] Holton, C. S.—Hybridization and segregation in the oat smuts—Phytopathology 21: 835-842. 1931.

[61] Tapke, V. F.—Seed treatments with chemical dusts and formaldehyde for smut control in oats—Phytopathology 22: 429-441. May, 1932.

OATS

Formaldehyde dip was the most effective, having completely eliminated smut.

DuBay dusts Nos. 655 and 665 reduced smut to 0 in 1930 and to 1/100 of 1 per cent in 1931.

Smuttox, Kantsmut, and Corona Oat Dust reduced smut to 1 per cent or less.

Ceresan produced excellent control.

K-I-C produced fairly satisfactory control.

Ansbacher Grain Dust and Wa Wa Dust produced unsatisfactory control in the first sowing but were otherwise effective.

Abavit B, Acco, Anchor Sulfur; D.D.D. No. 68; Niagara sulfurs 76, 77, 78 and 79; Sterocide, Tillantin Höchst, and Tutan were unsatisfactory.

The formaldehyde dip (seed immersed for ten minutes in a 1 to 320 formaldehyde-water solution, followed by draining off excess solution, covering seed over night, and aerating several days after treatment) reduced emergence about 4.5 per cent.

In another report[62] gains of 7 to 32 per cent in yield were obtained from the use of dust treatments. DuBay No. 952 C gave 32.5 per cent gain; Ceresan 23 per cent gain; formaldehyde 17.7 per cent gain. Merko was unsatisfactory, giving a decrease of 3 per cent as compared with untreated seed.

Leaf Rust *(Puccinia coronata avenae)*
Stem Rust *(Puccinia graminis avenae)*

Of the two rusts of oats, leaf rust and stem rust, the former is the more important. The general appearance of the rusts is like that of leaf rust (Page 200] and stem rust (Page 201) of wheat, respectively.

Control

Resistant varieties of oats offer the most practical means for combating rusts, and work is progressing in several experiment stations on the development of such varieties. Selections from a cross between Victoria and Richland varieties are said to be resistant to leaf rust, stem rust, and smuts.[63] White Russian (White Tartar) is another variety which is reputed to be resistant to stem rust.[64] Most strains of Red Rustproof oats are somewhat resistant to leaf rust and smut; Fulghum is less resistant to the same diseases.[65] Descriptions of other resistant

[62] Young, V. H. and McClelland, C. K.—Control of oat smut. Phytopathology 23: 825-830. 1933.

[63] Stanton, T. R.; Murphy, H. C.; Coffman, F. A.; Humphrey, H. B. Development of oats resistant to smuts and rusts. Phytopathology 24: 165-167. 1934.

[64] Arthur, J. C.—Plant rusts. John Wiley and Sons. New York. 1929.

[65] Stanton, T. R. and Coffman, F. A. Fall-sown oat production. U. S. D. A. Farmers' Bulletin 1640. 1930.

OATS

varieties of oats are given in U. S. D. A. Farmers' Bulletins 1640 and 1583.

PEAS

Field peas are grown in this State on a very small acreage but they produce satisfactorily, especially in the cooler districts. Few diseases of the crop have been reported or observed.

Bacterial Blight *(Phytomonas pisi)*

Bacterial blight has been found on canning peas in central Arizona[66] and may occur on field peas. Losses are caused by the death of young plants and the leaves, stems, flowers and pods of older plants.

Symptoms

Small, water-soaked spots appear on the green parts of the plant, often near the soil line, enlarge, kill the tissues, and turn brown to black. They may develop upward from the base or be scattered over the lower part of the vine. Young plants wilt and die (Fig. 36); older plants become yellowed. Flowers and

Fig. 36.—Bacterial blight of peas. The seedlings at the right were inoculated with the germ of the disease eight days before the photograph was taken; seedlings at the left were not inoculated.

[66] Brown, J. G. and Evans, M. M.—Diseases of peas in Arizona—Ariz. Agr. Exp. Sta. Bul. 142. Jan., 1933.

young pods are killed; older pods have round, water-soaked spots or a water-soaked strip along the back. The bacteria may penetrate through the pod into the seed.

Cause

Bacterial blight of peas is caused by a germ called *Phytomonas pisi* which can live for ten months or longer in the seed. The parasite is spread by wind, rain, irrigation water, contact of diseased with healthy plants, and in other ways.

Control

The use of clean seed and seed treated with organic-mercury dust, or with a solution of 1 pint of 40 per cent formaldehyde in 22 gallons of water for 20 minutes, are suggested for reducing losses from bacterial blight. Seed which looks healthy may have bacteria on the surface or within, therefore treatment is advisable.

Fusarium Foot and Root Rots and Wilt *(Fusarium spp.)*

Peas are subject to rots of the root and basal part of the stem, also to wilt, caused by species of the fungus, Fusarium. Details of the symptoms vary somewhat; the usual result of attack is the death of the plant, either with or without marked wilting. In foot rot the base of the stem and the upper part of the main root are rotted and discolored brown (Fig. 37); in wilt the wood bundles become clogged with the fungus, which interferes with the upward movement of water, and the plant also appears to be injured by poisonous excretions of the fungus. Wilting of the vine may be rapid, slow, or absent, depending upon the conditions surrounding the plant as well as the extent of infection. Instead of wilting there may be noticed a yellowing and withering of the leaves. A Fusarium foot rot of peas has occurred in central Arizona,[67] but wilt has not been reported for the State.

Until varieties of field peas are available which are resistant to Fusarium diseases, rotation with crops other than peas should be practiced on infected soil for four or five years. Infected vines should not be left in the field or distributed over fields in manure.

Powdery Mildew *(Erysiphe polygoni)*

This disease is a very common one on peas. Unlike downy mildew it withstands dry weather.

[67] Brown, J. G. and Evans, M. M.—Diseases of peas in Arizona—Ariz Agr. Exp. Sta. Bul. 142. January, 1933.

[68] Brown, J. G. and Evans, M. M.—Diseases of peas in Arizona—Ariz Agr. Exp. Sta. Bul. 142. January, 1933.

PEAS

Fig. 37.—Advanced stages of Fusarium foot rot in seedlings of Canadian field peas. a. Lesions which have almost severed the taproot; b. lesions progressing upward on the stem.

Symptoms

Pea vines affected by powdery mildew show a white mold on stems, leaves, and pods (Fig. 38). Diseased parts may become yellow; badly infected plants are dwarfed and killed.

Control

Although Bordeaux mixture and sulphur dust control powdery mildew on peas, the cost usually makes spraying and dusting impractical. Rotation of crops has not given satisfactory results.

PEAS

Fig. 38.—Powdery mildew *(Erysiphe polygoni)* on the pea. a. Powdery coating of spores on the petiole; b. on a stipule; c. coating of fungous filaments on pod and stipule.

Rhizoctonia Root Rot *(Rhizoctonia solani)*

This disease attacks many crops including peas and the symptoms are similar. Plants infected with Rhizoctonia at first appear to be stunted; later they show yellow leaves; death often follows. The root and the base of the stem show small, light brown, somewhat irregular spots (Fig. 39) which later become sunken and dark brown. Infected roots are constricted (Fig. 40). Young plants are killed but those which escape infection until they are well past the seedling stage usually survive.

Control

The fungus which causes Rhizoctonia root rot can live in the soil on decaying matter and also on the roots of weeds; therefore it is difficult to control. Clean cultivation, the destruction of weeds, good drainage, and careful preparation of the soil before

PEAS

Fig. 39.—Rhizoctonia lesion, "l," on base of stem of pea plant.

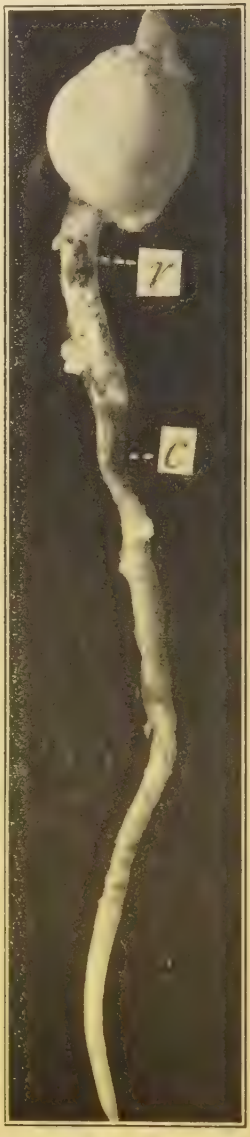

Fig. 40.—Root of pea plant with Rhizoctonia disease: c. lesion or decayed spot; r. resting body of fungus.

sowing are valuable control measures. Peas should not follow potatoes, cotton, or beans which have shown extensive infection with Rhizoctonia. Too frequent irrigation of peas on the heavier soils is favorable to the disease.

For a more comprehensive discussion of Rhizoctonia root rot, see Bulletin 142 of this Station, which also takes up such physiological troubles as drought, hail and alkali injury.

Root Knot *(Caconema radicicola)*

Root knot is a disease affecting not only peas but most other crops excepting grasses and grains. For details concerning the disease on peas, consult Bulletin 142 of the Arizona Agricultural Experiment Station.

Fig. 41.—Dwarfing of field peas caused by root knot. Infected plants at the sides, healthy plants in center.

Symptoms

Since the general symptoms described on pages 152-154 apply to other susceptible crops they will be omitted here. In examining the roots of legumes such as peas for root knot, care must be

PEAS

taken not to mistake the beneficial bacterial nodules for the harmful galls. Nodules are *on one side* of a rootlet; the galls are *inside* the root or rootlet (Fig. 42).

Fig. 42.—Root-knot galls, "n," and bacterial nodules, "y," on roots of field pea. Magnification nearly three times, as shown by the vertical line at right.

Control

See pages 154-155.

Texas Root Rot *(Phymatotrichum omnivorum)*

Peas are susceptible to Texas root rot which attacks many wild and cultivated plants. The symptoms of the disease on peas are similar to those described for other susceptible crops and the same control measures apply (Pages 160-161).

RED CLOVER

The crop is grown to a very limited extent at the higher altitudes in Arizona. Few if any complaints regarding plant diseases on clover have been received. Clover is susceptible to Pseudopeziza leaf-spot caused by a fungus closely related to the one which attacks alfalfa and called *Pseudopeziza trifolii*. The symptoms are similar to those on alfalfa (Pages 120-121). Rust *(Uromyces trifolii)* also attacks red clover and has an appearance similar to the rust of alfalfa (Pages 121-123). Other diseases are bacterial streak *(Erwinia lathyri)*, powdery mildew *(Erysiphe polygoni)*, dodder *(Cuscuta spp.)*, root knot *(Caconema radicicola)* and several additional troubles. None of the diseases mentioned have been observed or reported in this State, so far as our records are concerned, although the commoner ones like leaf-spot, rust, and powdery mildew are probably present at times.

RYE

Rye is grown to a very limited extent in Arizona. The total annual planting probably does not exceed 300 acres. The crop is grown only in the northern counties where most of it is either cut for hay or turned under for green manure.

Ergot *(Claviceps purpurea)*

Although this old, well known disease of rye has not been reported in Arizona, it is included here in order that it may be recognized if it should reach the State. Wherever it occurs the disease is important not only for its effect on the crop, but also on account of its effect on livestock.

Symptoms

Hard, black or violet, horn-like bodies (sclerotia) replace some of the grains in the head of rye (Fig. 43); other grains and florets are blasted. Diseased heads are shorter and lighter than normal heads and this condition reduces the yield.

Cause

The fungus which causes ergot of rye is called *Claviceps purpurea*. Spores of the fungus, carried by wind and insects at flowering time, germinate on the flowers of rye and send fungous threads into the developing seed which becomes molded. At this time a sticky substance called honey dew is found on the heads. The honey dew contains many spores and attracts insects which carry the spores to other plants. Later the fungous threads in infected kernels grow out into the hard club or horn-like body which often falls to the ground when ripe. This body, the sclerotium, can overwinter in the soil. In spring it sprouts into a number of bodies which somewhat resemble a pin with a rounded head and straight or bent shaft. These bodies form another kind of spore which infects the new crop of rye when it blossoms.

RYE

Fig. 43.—Ergot attacks grains and grasses: upper left, barley; lower left, rye; center, brome grass; right, wheat grass. x 0.9.

Other Hosts

Besides rye ergot also attacks many varieties of wheat as well

RYE

as barley, oats, and species of certain wild grasses [69] including brome grass, orchard grass, Colorado blue stem, wild rye, slender wheat grass, and feather grass (Fig. 43).

Effect on Livestock

Animals which are fed ergotized grain and which pasture on infected grasses have poor circulation of the blood, high blood pressure, and other disorders. Abortion is also caused by the ergot fungus. Horses are less susceptible to the poisonous alkaloids of ergot than cattle.

Control

Clean seed and proper rotation of crops together with the destruction of susceptible weeds control ergot of rye.

OTHER DISEASES

Powdery Mildew *(Erysiphe graminis secalis)*; Stem Rust *(Puccinia graminis secalis)*; Leaf Rust *(Puccinia dispersa secalis)*.

Rye is susceptible to other diseases, including powdery mildew (Page 132), stem rust (Page 201), and leaf rust (Page 200), but it seldom shows these diseases in Arizona. Two promising selections from Abruzzes rye (S 2229) which are highly resistant to the diseases mentioned are reported by Mains.[70] Take-all (Page 204), bunt (Page 196), and loose smut (Page 199) also attack rye.

SESAME

Bacteriosis *(Phytomonas solanaceara)*

Sesame has recently been planted on a small acreage in Arizona; only one disease of the crop has been determined. This disease corresponds in symptoms with Malkoff's bacterial disease[71] attributed by several investigators to *Phytomonas solanaceara*. From the infected plants a bacterium has been isolated which answers to the description of the organism referred to.

Symptoms

The whole sesame plant above ground or single shoots may show the disease (Fig. 44). Both leaves and stem are attacked. On the leaves brown spots appear; the leaves die and dry out. Stems become discolored dark brown to black; a gray, slimy bacterial ooze may flow out, dry on the stem, and become black.

Control

The bacterium which causes the disease is carried on the seed. In Arizona plants from untreated seed have become diseased, but a healthy stand has been obtained by immersing the seed in a

[69] Mains, E. B.—Observations concerning the disease susceptibility of cereals and wild grasses—Proc. Ind. Acad. Sci. 34: 289-295. 1924 (1925).

[70] Mains, E. B.—Rye resistant to leaf rust, stem rust, and powdery mildew—Jour. Agr. Res. 32: 201-221. 1926.

[71] Malkoff, Konstantin—Eine Bakterienkrankheit auf Sesamum orientale in Bulgarien—Centralblatt für Bakteriologie und Parasitenkunde 11: 333-336. 1904.

SESAME

1:1,000 solution of mercuric chloride. Planting was made the first week in July by Professor Ian A. Briggs of the Department of Agronomy. Although not a single diseased plant was found in the plot from treated seed, 10 per cent or more of those from untreated seed died and many were dwarfed. The bacteriosis in the plants from untreated seed appeared about September 20.

Fig. 44.—Bacteriosis of sesame (after Malkoff). A. Progressive stages in the disease, 2, 3, 4, compared with healthy plant, 1. B. Healthy plant bearing pods, left, and two sick plants at right.

SESBANIA

Sesbania is used for a green manure crop in the Yuma and Salt River Valleys and in other cotton growing districts. Although the crop is known to be susceptible to Texas root rot and other diseases, no losses have been reported to this Department. Like certain other green manure crops, Sesbania keeps the root-rot parasite alive and should not be planted where eradication of the rot is attempted.

SORGHUMS

Bacterial Streak *(Phytomonas [Bacterium] holcicola)*

Bacterial streak of sorghums was first encountered in Arizona in the season of 1933, having been sent to this laboratory from the Mesa district on September 13. The host plant was milo maize. The disease had previously been reported from Kansas, Montana, Oklahoma, and Texas. Besides sorghums, Johnson grass is susceptible.

Symptoms

Long, narrow water-soaked streaks which may be short or several inches in length, appear on the leaves. This water-soaked stage may be overlooked by untrained observers. Soon the streaks become red and they may broaden into spots with red margins and tan-colored centers. Bacterial ooze may appear in drops on the surface of the streaks and dry in the form of white or pale yellow scales. The plants sent to us had most of the upper leaves killed and dried throughout one-fourth to two-thirds of their length; they bore dwarfed heads.

Cause

The streak disease of sorghums is caused by a recently described[72] bacterium which, it is suggested, possibly spreads either on the seed or by means of soil.

Bacterial Stripe *(Phytomonas andropogoni)*

Bacterial stripe of sorghums should not be confused with bacterial streak (See above). Stripe has been known for approximately fifty years, although the cause was not certain until 1911. The disease is widespread and attacks broomcorn, sorgo, and grain and grass sorghums.

Symptoms

Red streaks and blotches from very short to several inches in length appear chiefly on the leaves but may extend to the stalks. The spots are either blunt or jaggedly pointed and the form is always the same regardless of the variety of the infected sorghum.

[72] Elliott, Charlotte—Bacterial streak disease of sorghums - Jour. Agr Res. 40: 963-976. 1930.

SORGHUMS

Fig. 45.—Bacterial streak disease of sorghum: infections on Dwarf White Milo (after Charlotte Elliott).

The shade of red, however, varies from dark purplish red on chicken corn, Early Amber, Silvertop, Sudan grass and Sugar Drip, to light brick-red on Red Amber and brownish red on Kafir. The red color is always continuous throughout the spot, never marginal. Excepting a few varieties of sorghum and shallu, crusts of dried bacterial ooze on the under side of the spots are red; in the exceptions noted the crusts are yellowish brown.

SORGHUMS

Fig. 46.—Bacterial stripe disease of sorghum on parts of two leaves. The lesions have ends which are either blunt, "a," or extended into long jagged points, "b," (after Charlotte Elliott).

Cause

Stripe of sorghums is caused by a white bacterium called *Pseudomonas andropogoni*. The parasite grows best at temperatures

of 72 to 86 degrees F.; it ceases growth at a minimum temperature of approximately 41 degrees F. and at a maximum temperature of approximately 100 degrees F. The parasite is spread by wind, water, and possibly by insects. There is evidence that the bacterium is carried on the seed. When it reaches a susceptible plant the parasite can enter through the breathing pores (stomata) and through wounds.

Resistance

In experiments conducted by Elliott[75] at Arlington, Virginia, the following varieties showed either no infection or strong resistance to the bacterium of stripe: Among the grain sorghums, Gray Kafir, Texas Gooseneck, Blackhull Kafir, Chicken Corn, Yellow Milo, Dwarf White Milo, Feterita, Manchu Kaoliang, Shallu. Proso (Early Fortune) showed no infection; neither did a selection of white sorgo and a selection of Sudan grass.

Control

Although bacterial stripe usually causes small loss, it is capable of killing much of the leaf surface in moist warm weather. Whenever possible resistant varieties should be planted. Seed treatment is a good form of insurance, especially since the same treatment protects against certain smuts (Page 188).

Covered Kernel Smut *(Sphacelotheca sorghi)*

Although covered kernel smut is found in all parts of Arizona where grain and forage sorghums are grown, it occurs sporadically; at times large fields or even entire districts may be free from infection.

The disease is caused by *Sphacelotheca sorghi*, a fungus with a life history similar to that of covered smut of wheat (Page 196). Infection occurs only in the seedling stage from spores on the seed or in the soil. The germinating seed becomes infected; the fungous filaments reach the growing point and keep up with the growth of the sorghum plant until they get into the young flower. Instead of grains, masses of the covered kernel-smut spores then develop.

Symptoms

Like the covered smut of wheat, the covered kernel smut of sorghum does not appear until the flowers have been fertilized and the grain is filling. At that time infected heads of the hegari and milo types look more compact and slenderer than healthy heads; they are also different in color. Upon close examination it will be noticed that the individual kernels have become replaced by dark brown to black powder enclosed in a thin, whitish membrane. The powder consists of the smut spores. As the

[75] Elliott, Charlotte and Smith, Erwin F.—A bacterial stripe disease of sorghum—Jour. Agr. Res. 38: 1-22. Jan. 1, 1929.

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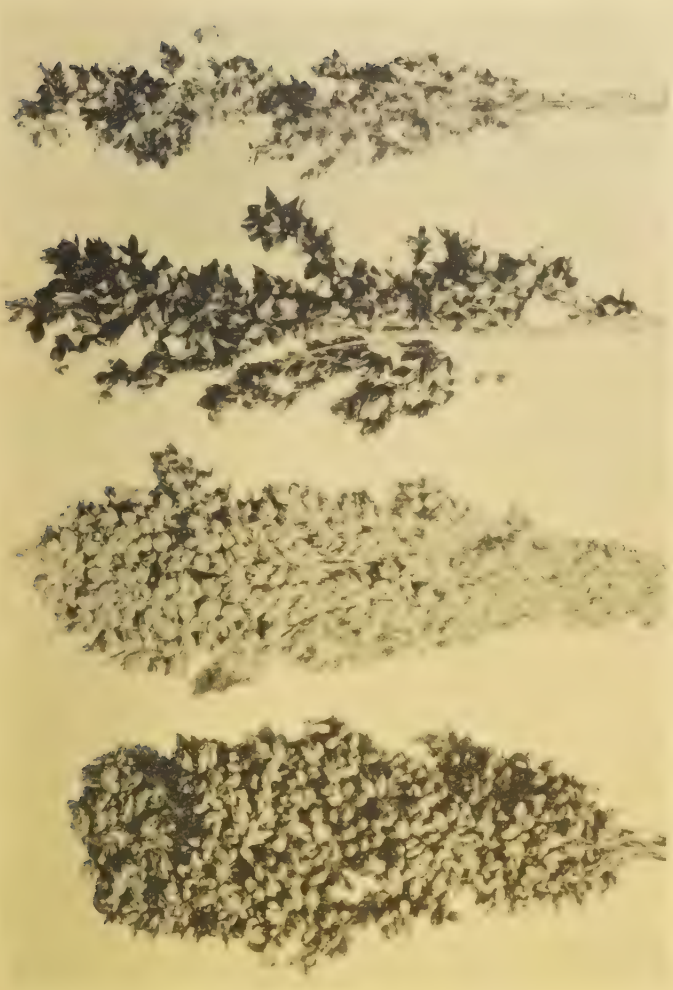

Fig. 47.—Kernel smut of sorghums. The individual grains are replaced by smut balls. Varieties, left to right: Sumac, Black-hulled White Kafir, Black Amber, Amber. x 0.4.

season advances a few membranes are broken by weathering and the whole smutted head becomes dark. Each infected kernel is longer and slenderer than the healthy, almost round, normal grain (Fig. 47).

Toxicity

The reaction caused by inhaling the smut spores in handling and threshing sorghum grain has led to the belief that the smut is poisonous when fed to livestock. Inhaling of air containing smut spores causes the air passages of man to be sensitive to breathing, increases the action of the heart, and is followed by headache and partial nausea. These effects wear off in a few hours. Careful feeding experiments[74] have shown that neither large animals such as horses, cows, and young livestock, nor smaller livestock such as poultry and rabbits, are injured by the feeding of as much as 10 per cent of smut spores.

Control

Covered kernel smut and loose kernel smut (see below) of sorghums are easily controlled by the copper-carbonate seed treatment used for covered smut of wheat. Two ounces of copper carbonate containing 50 per cent copper, or 4 ounces of copper carbonate containing 20 per cent copper are used per bushel of grain. To be effective the copper carbonate dust should be applied with a machine (see page 214). The formaldehyde treatment is effective but more troublesome in application, and it invariably causes some seed injury.

Milo maize is resistant to most sorghum smuts, although kafirs and sorgos or sweet sorghums are quite susceptible. In 1923 a kernel smut was found on milo and hegari in northeastern New Mexico and adjacent parts of Texas and Kansas.[75] The fungus concerned is probably a more pathogenic strain of *Sphacelotheca sorghi*, but it may be a hybrid with *Sphacelotheca cruenta*, the cause of loose kernel smut, since it shows some characteristics of the latter. The fungus is of interest because it attacks varieties of sorghums thought to be resistant to smuts as well as the more susceptible varieties.

Loose kernel smut, caused by a fungus similar to that concerned in covered kernel smut and known under the name of *Sphacelotheca cruenta*, has not been found in Arizona, although it occurs in New Mexico and states eastward.

Head Smut *(Sorosporium reilianum)*

Head smut of sorghum has been reported from all continents; although it occurs in Arizona the disease is as yet relatively un-

[74] Heller, V. G.; Caskey, C. and Penquite, R.—The possible toxicity of grain-sorghum smuts—Jour. Agr. Res. 40: 347-351. 1930.

[75] Tisdale, W. H.; Melchers, L. E., and Clemmer, H. J.—Strains of kernel smuts of sorghum, Sphacelotheca sorghi and S. cruenta —Jour. Agr. Res. 34: 825-838. 1927.

important. That it may cause considerable damage is evidenced by a loss of 15 per cent reported on Orange Sorgo at Davis, California.[76]

Fig. 48.—Head smut of sorghum. x 0.5.

[76] Mackie, W. W.—Head smut in sorghum and maize. Phytopathology 10: 307-308. 1920.

SORGHUMS

Symptoms

Smutted and healthy plants are alike until the heads begin to form; infected plants have smaller heads than healthy plants. Head smut affects the whole head of sorghum, rarely only a part; never single grains. At first the mass of smut is covered with a gray membrane which soon disappears. The naked spores are then scattered leaving a stringy mass (Fig. 48) which consists of the wood fibres of the head.

Infection

Spores of head smut are carried on the grain and also remain alive in the soil. Seedlings become infected in dry soil at soil temperatures between 61 degrees F. and 97 degrees F., but a temperature of 82 degrees F. is most favorable.[77] The severity of infection is influenced not only by temperature but also by moisture. No infection occurs in moist soil at 61 degrees F. High soil moisture reduces the percentage of smutted plants.

Hosts

Head smut attacks certain sorghums and corn.

Control

Seed treatment with a good fungicide (Pages 213-217) should reduce infection on clean soils. Where the soil is heavily contaminated with the spores of head smut, rotations should be used from which susceptible sorghums and corn are omitted; such rotations must extend over a period of several years. Feteritas, milos, kafirs, kaoliangs, and most durras are resistant.[78] Among the more susceptible varieties of sorgos are Red Amber, Black Amber, Minnesota Amber, Colman Sorgo, Early Rose Sorgo, Schrock Sorgo, Brown Durra and White Durra.

Rust *(Puccinia purpurea)*

Sorghums are subject to a rust caused by *Puccinia purpurea* which, since it occurs in California and Texas, may reach Arizona at any time.

Symptoms

Bright purplish-red spots more or less cover the surface of the leaf. In the spots pustules develop which are brown to red in color, elongated lengthwise of the leaf, and situated between the veins. The pustules may be scattered or grouped. They are covered at first by the skin (epidermis) of the leaf, but later they break out like the pustules of wheat rust (Page 201); then the summer spores of the rust are shed in the form of a light brown

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[77] Christensen, J. J.—Sorghum head smut—Phytopathology 16: 353-357. 1926.

[78] Reed, George M. and Melchers, Leo E.—Sorghum smuts and varietal resistance in sorghums—U. S. D. A. Department Bul. 1284. 1925.

Fig. 49.—Soybean. A. Experimental plot of Virginia variety injured by burning or sunscald. Photographed Oct. 4, 1921. B. Soybean leaflet showing burning at "o," followed by attack of Alternaria fungus at "f." Photographed March 7, 1921.

SORGHUMS

powder. Similar pustules which are deep reddish brown develop later. They shed the deep brown, winter spores of the rust when they are ripe.

Hosts

Sorghum rust attacks not only sorghum but also Johnson grass, Sudan grass, and related varieties and species.[79]

Control

When varieties of sorghum resistant to rust are available control will be practical. In the United States sorghum rust does not as yet constitute a major disease; in India[80] its destructive nature appears to be explained by the practice of growing repeated crops of sorghum on the same soil throughout the year.

SOYBEAN

Although soybeans are susceptible to several parasitic diseases including bacterial wilt (Page 181), powdery mildew (Page 173), root knot (Page 177), Texas root rot (Page 159) and stem rot (caused by *Rhizoctonia solani*), sunburn has been more serious and most varieties are also susceptible to hot, dry winds.[81] The Biloxi variety appears to be better adapted to the climatic conditions in southern Arizona than Otootan, Virginia (Fig. 49A), Mandarin, Barchet, Shanghai, Tokio and Peking varieties. Symptoms of sunburn and wind injury are a browning or bronzing of the leaf, especially along the margin; the color may become almost brick-red. Following the sunburn, a species of *Alternaria* often grows in the leaf and covers the injured surface with a sooty layer of spores (Fig. 49B).

SUDAN GRASS

Covered Kernel Smut *(Sphacelotheca sorghi)*

Sudan grass is moderately susceptible to covered kernel smut of sorghum (Page 186); loose kernel smut appears not to have been reported on this host. The crop is also susceptible to head smut (Page 188).

WHEAT

Basal Glume Rot *(Phytomonas atrofaciens)*

Basal glume rot of wheat[82] is a disease of relatively minor importance but general distribution in the states between the Mississippi River and the Rocky Mountains; it is also reported from Michigan, New York, and Pennsylvania.

[79] Arthur, J. C.—Plant rusts, p. 339—John Wiley & Sons, N. Y. 1929.

[80] Butler, E. J.—Fungi and disease in plants, p. 207—Thacker, Spink & Co., Calcutta. 1918.

[81] Gibson, Frederick—Sunburn and aphid injury of soybeans and cowpeas—Ariz. Agr. Exp. Sta. Tech. Bul. 2. Sept. 15, 1922.

[82] McCulloch, L.—Basal glume rot of wheat—Jour. Agr. Res. 18: 543-551. 1920.

WHEAT

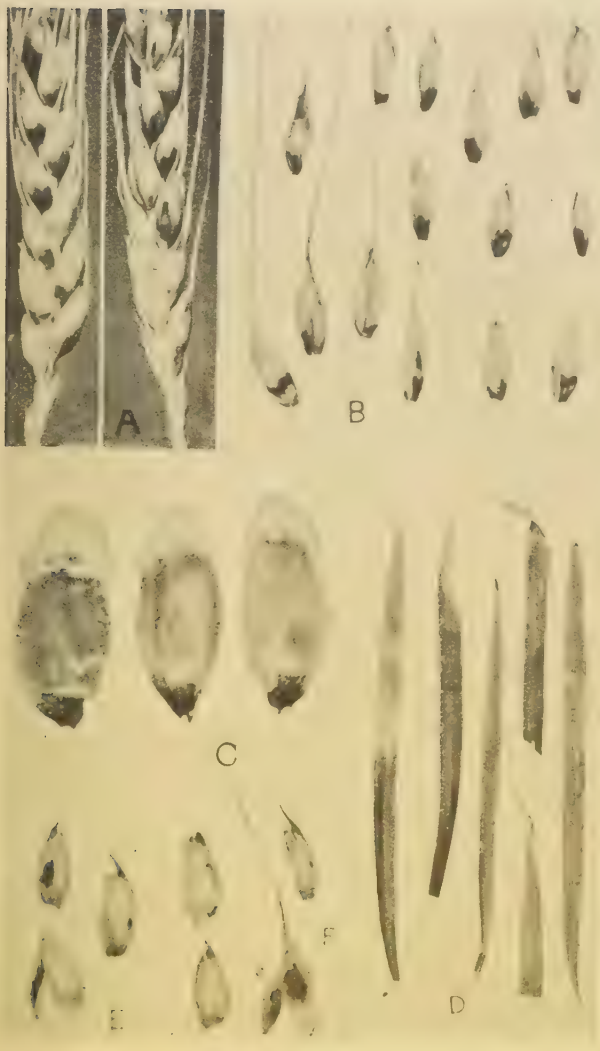

Fig. 50.—Basal glume rot of wheat. Note dark lesions on base of glumes in "A" and "B," and black tips of kernels in "C" (after McCullough).

Symptoms

Glume rot affects the heads, grain and leaf of the wheat plant (Fig. 50). On the heads the glumes show a dull brownish to

black discoloration which usually covers only the lower third, or less, of the glume; often no discoloration is visible from the outside. The grains of wheat under infected glumes show infection of the germ-end which varies in color from faint brown to charcoal black. In case of early infection the development of the grain is checked, but grains infected near maturity show only discoloration. The leaves first have dark water-soaked spots which turn pale yellow, then yellowish brown, followed by shrivelling.

Cause

Basal glume rot is caused by a bacterium, *Phytomonas atrofaciens.*

Control

Wheat which shows more than a trace of germ discoloration should not be used for seed. Direct control of the disease in the field is not practical.

Black Point

In certain years a blackening of the germ-end of wheat kernels is prevalent in Arizona wheats. The disease was especially noticeable in 1925 and 1926, but has been less noticeable since that time.

Symptoms

The kernels are usually bright in color except that portion covering the embryo which shows a brownish, creosote-like discoloration. Some kernels are scarcely visibly affected, although others show a discoloration of the endosperm as well as the embryo. The lower part of the embryo is most uniformly affected. The presence of all degrees of discoloration makes difficult an accurate estimate of the percentage of infection. Counts from 0.1 per cent to 90 per cent have been made, but 10 per cent is the usual maximum.

Cause

Black point in Arizona wheat may not be identical in cause with the disease bearing the same name in Canada and the northern states of the Mississippi Valley. Evans, working in Ontario, found the fungus, *Helminthosporium sativum*, on 77.6 per cent of infected grains; Henry in Minnesota found *H. sativum* in 73.5 per cent of black-pointed grains, also a species of *Alternaria* in 10.6 per cent of his cultures, and several other species of fungi in the remaining cultures.

Cultures of wheats grown in Arizona by the junior author have shown very little *H. sativum* but in some instances 92 per cent of the cultures developed *Alternaria.* In addition 72 per cent also showed *Penicillium sp.* (a blue mold), but this fungus is regarded

as a secondary organism. Under laboratory conditions 70 per cent of the black-pointed kernels gave apparently normal germination and 22 per cent failed to germinate. Under field conditions a lower percentage would survive.

Fig. 51.—Wheat smuts. Left: covered smut-balls and infected head with glumes spread by smut-balls; center, loose smut; right, healthy head. x 0.6.

WHEAT

Control

Since infection appears to depend upon abundant moisture during the filling and ripening period of the wheat, direct control is probably impossible.

Bunt, Stinking Smut *(Tilletia tritici; T. levis)*

Bunt or stinking smut of wheat reduces the yield, renders the grain unfit for flour unless it is scoured, and causes explosions in threshing machines which often result in serious fires. The disease, which has been known since very early times, is found wherever wheat is grown. Losses caused by bunt vary from year to year, but the decrease in yield of wheat in the United States due to smut amounts to about 25,000,000 bushels annually. Of approximately 539,000 carloads of wheat marketed at various terminals in this country between July 1, 1931, and June 30, 1932, and inspected by the agents of the Federal Grain Supervision,[1] more than 40,000 carloads were classed as smutty Bunt is bad in Arizona.[2]

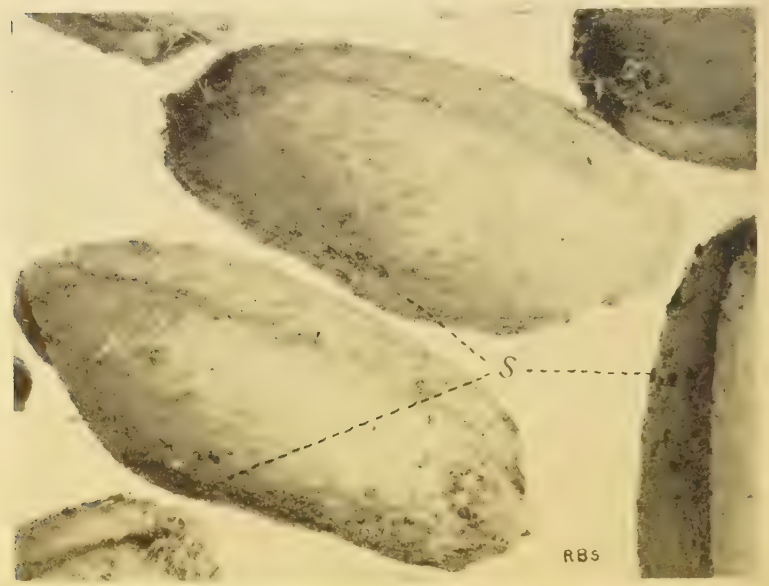

Fig 52.—Smutted wheat grains enlarged to show many spores, "s," of the bunt fungus adhering to the surface.

[1] Boerner, E. G. and Haskell, R. J.—Smutty wheat—U. S. D. A. Rept. 17. 1932.

[2] Brown, J. G.—Bunt of wheat—Ariz. Agr. Exp. Sta. Timely Hints for Farmers 143. Apr. 15, 1923.

WHEAT

Cause

Bunt of wheat is a fungous disease which may be caused by either of two species of fungi, *Tilletia tritici* or *Tilletia levis*. The former species is the common bunt fungus in Arizona. Spores of the fungus are rough and brown in color when viewed singly under the lens, but black in masses large enough to be seen with the naked eye. Under favorable conditions a spore germinates in the soil into a short tubular plant with a group of slender, secondary spores at the tip (Fig. 53). From the second set of spores an infection thread may be sprouted which directly enters the wheat seedling, or branches may arise which produce small spores called sporidia (Fig. 53). The sporidia then send infection threads into the wheat seedling. Although the fungus can enter an older plant through wounds,[1] in nature only the seedling appears to become infected.

Fig. 53.—Stages in the germination of a smut spore (*Tilletia tritici*). After Brown, reference 84.

[1] Bodine, E. W. and Durrell, L. W.—Inoculation of wheat with Tilletia levis (Kuhn).—Phytopathology 20: 663-667. August, 1930.

WHEAT

Source of Infection

In Arizona the source of infection of wheat with the bunt fungus is the spores on the seed grain (Fig. 52). This is an important fact to remember: if the seed is treated with a good disinfectant which kills the spores there can be no smut. A different condition is found in regions where showers of smut spores set free in threshing contaminate the soil at the time when wheat is sowed. Where smut showers occur seed treatment may have little or no effect in controlling bunt. Another fact should be noted here: if the seed grain is not cleaned of smut balls, the spores remaining in the balls may not be killed by the seed treatment and smut may result, even though the seed is treated.

Symptoms

Wheat infected with bunt often has a stunted, bluish green appearance which extends to the heads as well as the stems and leaves. The false grains are so large that they push the chaff outward farther than in healthy heads, so that the infected heads have a looser appearance (Fig. 51). When they are ripe the heads show the dark smut balls instead of the lighter brown kernels, and the smut balls when broken expose almost black masses of smut spores which have the well known odor of decaying fish.

Control

The older methods for the control of bunt made use of formaldehyde and copper sulphate. In recent years copper carbonate dust has superseded the wet treatments. Reasons for this and also details for seed treatment of wheat are given under "Seed Treatment" on pages 207-217.

Bunt-resistant wheats would be much more valuable for the control of bunt than seed treatment if good milling varieties could be found. However, most bunt-resistant wheats make inferior flour. Brentzel and Smith[58] state that "in general, the durum wheats were found to be about 100 per cent more susceptible to *Tilletia tritici* than *T. levis;* the hard red spring wheats were about 100 per cent more susceptible to *T. levis* than to *T. tritici.* Average resistance of the durum wheats to both species of bunt was about 30 per cent greater than that of hard red spring wheats." Tisdale and coworkers[59] say that immune strains of Hussar and Martin wheats, although of little commercial value, are important for the development of bunt-resistant varieties by hybridization; Ridit, a hybrid between Turkey and Florence, may

[58] Brentzel, W. E. and Smith, Ralph W.—Varietal resistance of spring wheats to bunt—N. D. Agr. Exp. Sta. Bul. 231. July, 1929.

[59] Tisdale, W. H., Martin, John H., Briggs, Fred N., Mackie, W. W., Woolman, H. M., Stephens, D. E., Gaines, E. F. and Stevenson, F. J.—Relative resistance of wheat to bunt in the Pacific Coast States—U. S. D. A. Dept. Bul. 1299. Jan., 1925.

possibly become a valuable commercial variety; Sherman wheat, a resistant selection from Turkey, can safely be planted without seed treatment and equals the original Turkey wheat in yield.

Loose Smut *(Ustilago tritici)*

Losses caused by loose smut of wheat are less than those caused by bunt, although they may be severe under conditions favorable to the disease. Estimates place the former at 2 per cent or less. Since the infected plants are evident for only a short period (flowering time) they are frequently overlooked; therefore estimates of loss may be too low.

Symptoms

When wheat is beginning to head, loose smut shows black, powdery masses which are first covered with a thin gray membrane but soon free. All heads of a single plant may be smutted, or some heads only, with others healthy; in a single head usually all spikelets, and exceptionally only the lower spikelets, are smutted. The smut soon blows away leaving only the central stalk (rachis) of the head before the field is ready for harvest (Fig. 51).

Infection

The loose-smut spores which reach the flowers of healthy wheat plants grow into the ovary and infect the seed. The parasite then becomes dormant until the grain is sowed; then it enters the seedling, lives in the growing plant, and again smuts the heads of the new crop. Since the fungus is inside the seed, treatments like those for bunt cannot control the disease for they do not reach the parasite.

Effect on the Plant

Wheat plants infected with the loose-smut fungus require one-fifth to one-fourth more water than healthy plants of the same age. For somewhat less than a month the infected plants really grow faster than healthy ones, then growth slows; at flowering time their dry weight is only about two-thirds that of normal wheat plants.

Control

A combination of the hot-water treatment (Page 208) and the seed-plat method is the only feasible control. Grain is disinfected by the former and then increased in the seed plat, because the treatment is too cumbersome to use on sufficient seed for large commercial fields. Another way to avoid loss from loose smut is to sow a resistant variety. Bearded wheats in general are more susceptible than beardless varieties. Leap Prolific, Harvest King, Gold Coin, Hussar, Ridit, Fultz, Strube's Silesian, Hungarian Theiss, and Wohltmann's Green are reported either as highly resistant or immune.

WHEAT

Orange Leaf Rust *(Puccinia triticina)*

Orange leaf rust, which is often found with stem rust (Page 201) but is less common in Arizona, is caused by *Puccinia triticina*. When it is abundant this rust causes considerable reduction in the yield of wheat.

Symptoms

The rust is rarely found on parts other than the leaves; the pustules are round or oval, scattered, bright orange when fresh and darker with age. The black-rust stage occurs mostly on the under surface of the leaves; the pustules are flat and do not rupture the epidermis. The cluster-cup stage develops on meadow rue and other plants of the buttercup family.

Control

Of the possible control measures the development of resistant varieties of wheat appears to be the most promising. Twelve biological forms of the fungus have been found; also twenty-five strains of wheat which showed more or less resistance.[58] Dusting with sulphur has proven less effective in the control of leaf rust than with stem rust.

Rosette

Rosette is a disease of winter wheat which is important in parts of Illinois and Indiana; it has also been observed in Kansas, Nebraska, and Maryland.[59] Varieties of barley and rye are also susceptible. Rosette of wheat has not been observed in Arizona.

Symptoms

Infected plants show no symptoms in the fall but they are easily recognized in the spring by their marked stunting and rosetting in certain well-defined spots in the field. Affected plants show excessive tillering and a dull blue color which later turns to brown. Green and yellow types of mosaic have been observed.[60] Affected plants often die. Only the early seedling stage can be infected, either through the roots, the crown, or both.[60]

Cause

The cause of rosette is not definitely known, but the disease is

[58] Mains, E. B. and Jackson, H. S.—Physiological specialization in the leaf rust of wheat, *Puccinia triticina* Eriks.—Phytopathology 16: 89-120. 1926.

[59] Johnson, A. G., McKinney, H. H., Webb, R. W., and Leighty, C. E.—The rosette disease of wheat and its control.—U. S. D. A. Farmers' Bul. 1414. 1924.

[60] McKinney, H. H.—A mosaic of wheat transmissible to all cereal species in the tribe Hordeae—Jour. Agr. Res. 40: 547-556. Mar., 1930.

supposed to be a malady involving several viruses. The planting of resistant varieties of grains in infected areas is recommended.

Stem Rust *(Puccinia graminis tritici)*

Stem rust of wheat is a disease of world-wide distribution wherever wheat is grown and is very probably one of the "rusts" mentioned in Roman and Biblical writings. In most years stem rust is not common or destructive in Arizona, but spring rains on fall-planted wheat in the southern counties and summer rains on spring-planted grain in the northern counties may result in heavy losses in yield.

Host Plants

Stem rust is known to occur on nearly one hundred species of the grass family, including small grains (wheat, barley, oats, rye), forage grasses including timothy, and many wild grasses.[1] An alternate stage of the fungus occurs on the common barberry, an ornamental seldom if ever seen in Arizona. Bermuda grass, Johnson grass and Sudan grass are not susceptible to black stem rust.

A few years ago when a critical study was made of the relative susceptibility of different varieties of cereals to stem rust, it was found that strains of rust from different hosts and different localities did not behave alike although, under the microscope, they appeared to be identical. This led to the separation of the fungus into "biological strains," each with a definite host range. Further research showed that the strain on wheat was again divided into sub-strains or races, each of which could attack certain varieties of wheat but could not attack other varieties. This situation explains the difficulty of breeding rust-resistant varieties of wheat since not all the wheat strains are found in one locality, and wheat which is resistant to the strains of rust in one district may be susceptible to the strains of rust in another locality. In 1922 there were thirty-seven known strains of the wheat-rust fungus alone.[2][3]

Symptoms

Early in the season are found the elongated blisters or pustules which vary from one-sixteenth to three-sixteenths inch in length on wheat and grasses. As the pustules of this "summer" or "red-rust" stage mature, the epidermis of the leaf splits open showing

[1] Webb, Robert W. Further studies on the soil relationships of the mosaic disease of winter wheat. Jour. Agr. Res. 36: 53-75. Jan., 1928.
[2] Melhus, I. E., and Durrell, L. W. The barberry bush and the black stem rust of grains—Iowa Agr. Exp. Sta. Cir. 35. 1917.
[3] Stakman, E. C. and Levine, M. N. The determination of biologic forms of Puccinia graminis on Triticum spp. Minn. Agr. Exp. Sta. Tech. Bul. 8. 1922.

masses of reddish or rust-colored spores (Fig. 54). Later in the season, usually when the grain approaches maturity, similar elongated pustules of the "winter" or "black-rust" stage appear on leaves and leaf sheaths (Fig. 54). The reduction in yield is

Fig. 54.—Black stem rust of wheat: red rust (summer) stage at left; black rust at right. x 3.

directly proportional to the amount of rust present in the field.[94] Shriveled grains and poor quality of wheat result from heavy infection with rust.

The cluster-cup stage on the alternate host, the common barberry, shows as orange-colored spots thicker than normal leaf tissue and bearing on the under side many tiny round cups about one-fiftieth inch in diameter.

Life History

Although the wheat-rust fungus, *Puccinia graminis*, has five different types of spores, only the red-rust spores are important in Arizona. The life history in the northern states is briefly as follows:

The two-celled spores of the black-rust stage overwinter on straw and stubble and germinate in the spring, each cell producing four very small, air-borne spores which infect the young leaves of the barberry. On the barberry the rust fungus produces cluster cups. The cluster-cup spores from the barberry infect the young wheat plants on which the red-rust spores are formed which spread the rust on wheat. Thus the rust is spread very rapidly by the ripening of a new generation of red-rust spores every ten to fourteen days in favorable weather. Later the same and additional pustules of spores develop the black-rust spores.

In Arizona the rust cycle is much simpler, for the absence of the susceptible barberry leaves the black-rust spores nothing to infect. The rust fungus survives our relatively mild winters either in the red-rust-spore stage, or perhaps more frequently as fungous filaments in living tissues of grain plants or grasses. In fact the most critical time for the rust fungus in southern Arizona is the hot, dry summer period after grain has been harvested and susceptible volunteer grasses are scarce.

Control

Methods other than the eradication of the barberry as practiced in the northern states are necessary for our conditions.

1. The eradication or very close grazing of volunteer grains and susceptible grasses reduces the amount of infectious material but may not prevent rust, since the spores are carried long distances by the wind. Aeroplane experiments by Brown[95] and others show that the spores of many fungi are found at altitudes of 7,000 feet and over, which would enable the spores to travel long distances before reaching ground.

2. Immune varieties of wheat are satisfactory when they are developed in the region where they are to be planted. Both

[94] Goulden, C. H. and Greaney, F. J.—The relation between stem rust infection and the yield of wheat. Scientific Agr. 10: 405-419. 1930.

[95] Brown, J. G.—Living micro-organisms in the air of the arid Southwest—Science 72: 322-323. 1930.

Early Baart and Sonora, our principal varieties, are quite susceptible.

3. Experiments have been conducted in Minnesota[96] and Canada[97] with sulphur dust applied by aeroplane and ground machines for the control of rust. Applications of 20 to 50 pounds of sulphur dust at four- to five-day intervals, beginning when the rust first appears, give very satisfactory control. Frequent applications of 20 pounds per acre are more effective than heavier applications at longer intervals. Increases of yield up to 16 bushels per acre and the raising of grade from Number 3 to Number 1 at a cost of $5 per acre have been obtained,[97] but results do not always justify the expense. Aeroplane dusting is practical only for large acreages.

4. Early cutting of rusted grains has been advocated but careful experiments[98] show that largest yields and best quality are obtained by cutting at the usual time, in the hard-dough stage, two or three days before full maturity.

Take-All *(Ophiobolus graminis)*

The take-all disease of wheat was first discovered in the United States in 1919[99] but has now been found in most of the winter-wheat areas in the country. The losses range from a trace to 20 per cent of the yield. The disease has not been observed in Arizona.

Symptoms

The characteristic symptom is a dwarfing of all parts of the wheat plant including a reduction in height, number of tillers; extent of root system (Fig. 55); and size and amount of grain. The roots become black and brittle and the bases of the stems black and shining. At flowering time the plants are yellow, often with bleached "white" heads. Younger plants turn ashy white and die. Surviving infected plants produce very little grain.

Infected areas in the field vary in size from those with only a few plants to those 15 feet in diameter. The spots have a distinct margin caused by the sudden transition from short diseased plants to normal healthy ones.[100]

[96] Greaney, F. J.—Sulphur dusting for the prevention of cereal rusts—Report, Dominion Botanist, 1930, Div. Bot., Canadian Dept. Agr. pp. 61-66. 1931.

[97] Lambert, E. B. and Stakman, E. C.—Sulphur dusting for the prevention of stem rust of wheat—Phytopathology 19: 631-643. 1929.

[98] Greaney, F. J.—The influence on yield and grade of harvesting rusted wheat at different stages of maturity—Scientific Agr. 11: 492-511. 1931.

[99] Kirby, R. S.—The take-all disease of cereals and grasses—Phytopathology 12: 66-88. 1922.

[100] Fellows, Hurley—Wheat take-all symptoms compared with injuries caused by chinch bugs—Phytopathology 20: 907-909. 1930.

WHEAT

Fig. 55.—Take-all disease of wheat. Infected plants are stunted and the roots decayed. x 1/5

Cause

The cause of take-all is a fungus, *Ophiobolus graminis*, which attacks the roots and lower part of the stems and causes in them

WHEAT

a conspicuous discoloration. The strands of the fungus occur so abundantly between the culm and leaf sheath in the discolored parts that they form a solid plate of fungous tissue. Spores are produced in tiny perithecia (fruiting bodies). Infection is not carried in the seed but by fragments of diseased plants bearing fungous strands and spores. Barley, rye, and at least eight genera of wild grasses are also susceptible.

Control

A rotation of four or five years is the most satisfactory method of control. Seed wheat should be carefully cleaned before planting.

WHITE SWEET CLOVER; HUBAM

These crops are subject to attack by *Rhizoctonia* (stem rot), *Fusarium sp.* (root rot), *Phymatotrichum omnivorum* (Texas root rot), and *Caconema radicicola* (root knot); also by several other parasites. Care should be taken not to plant them where an effort is made to get rid of Texas root rot and root knot. Although only the Texas root-rot disease has been reported in Arizona, other diseases probably occur.

III. PREVENTIVE MEASURES

Prevention of plant diseases is much more important than their cure. Prevention may be inexpensive but the cost of curing disease in field crops, when cure is possible, is often prohibitive. Before preventive measures can be wisely applied the nature of a disease and its manner of dissemination must be understood.

Some diseases of field crops are disseminated by wind-carried spores and germs; others by reproductive parts which ride on or inside the seed; still others by the movement of the parasite through the soil in which it lives. Usually little can be done to prevent diseases in field crops when the disease-producing organism is carried through the air unless resistant plants of the desired kind of crop are available, although dusting with sulphur has been proved practicible in the control of wind-disseminated diseases like the stem rust of wheat. On the other hand seed-borne diseases can often be prevented by inexpensive seed treatments. Diseases which are caused by soil-dwelling parasites and by plant poisons called viruses make up a difficult group to handle, but even here prevention or control may be possible. Since dusting and the use of resistant plants have been mentioned in treating specific diseases, only seed treatments and the disinfection of the soil will be discussed.

SEED TREATMENTS

Seed treatment may be used for a special disease, or it may be applied as a general-purpose protection against several diseases. For instance the formaldehyde treatment kills germs and spores on the surface of the seed but the disinfectant soon evaporates; on the other hand, copper carbonate and other dusts not only kill surface-borne parasites but remain on the seed coat and retard the growth of fungi and bacteria in the soil which, under conditions unfavorable for the sprouting of the seed, might cause rot. Many seed treatments which originated in the study of some special disease were afterward found to protect against other diseases. Thus the sulphuric-acid treatment for cotton seed was originally used to prevent angular leaf-spot but subsequently found to protect against all surface-borne organisms on the seed. In order to know whether a seed treatment is likely to prove effective against a certain disease the nature of the disease must be known, including the life-history of the cause in the case of parasitic diseases.

When Can Seed Treatments Be Effectively Used?

Diseases in farm crops are caused by parasites which (a) are carried on the surface of the seed or (b) inside the seed, or (c) in the soil, or (d) in the air, or (e) in or on insects or other animals. Bunt or stinking smut of wheat is an example of a parasitic disease carried on the surface of the seed (Fig. 52); the fungus which causes loose smut of wheat enters the flower and gets inside the young grain; the loose smut of barley is carried in both ways, according to some investigators; Texas root rot comes into the roots of cotton, alfalfa, and other plants from the soil; rust of cotton and other plants is spread by spores in the air; virus diseases are often carried by insects. Although seed treatments may control diseases listed above under (a) and (b), they are useless for the control of diseases reaching the crop in the other ways mentioned.

Kinds of Seed Treatments

Seed treatments are classified as "wet" and "dry" of which the former are the older. Examples of the wet treatments are formaldehyde and copper sulphate dips for bunt of wheat; Jensen's hot water treatment for loose smut of barley and wheat, and the more recent organic-mercury solutions. The dry treatments make use of disinfectant dusts.

Although the old wet seed treatments are still used by some farmers, they have become almost universally replaced by the dusts in some instances, for example in the treatment of wheat for covered smut. One exception to the discarding of wet seed treatments is the hot-water treatment which remains the best

for seeds which contain parasites inside, such as barley seed infected with the loose-smut fungus. Used in connection with small, pure-seed plots, the hot-water treatment affords a means for increasing the yield that cannot be replaced by other methods.

Wet Seed Treatments

1. *Hot-Water Treatment.* This treatment is possible because the spores of certain parasites on seeds, as well as the parasite *inside* the seed, are killed at temperatures slightly below the temperature which kills the embryo in the seed. The hot-water treatment kills all spores of plant parasites, but *close attention must be given to the temperature in order not to kill the grain.*

Needed for the treatment are small, loosely woven cloth sacks or wire baskets which will hold ¼ bushel of grain; two barrels and two tubs; a double-burner gasoline or kerosene stove; an *accurate* thermometer. Instead of the stove a thermostat-controlled electric water heater should be used whenever possible. Mark the barrels "1" and "4" and the tubs "2" and "3." The following directions should be carefully observed:

a. Thoroughly clean the grain to be treated, or have it cleaned at an elevator or mill.
b. Soak the grain for 5-6 hours in water, Barrel 1.
c. Heat the water in Tub 2 to 110-112 degrees F.
d. Heat the water in Tub 3 to 125.6 degrees F. *for barley;* 129.2 degrees F. *for wheat.*
e. Fill Barrels 1 and 4 about ¾ full of cold water.
f. Put ¼ bushel of the soaked grain in a sack or basket and plunge the container in Tub 2 for 1 minute.
g. Quickly remove the container from Tub 2 and plunge it into Tub 3, for 13 minutes at 125.6 degrees F. *for barley* and for 10 minutes at 129.2 degrees F. *for wheat.* If the temperature of Tub 3 falls slightly the grain must be held in the tub for a proportionately longer time; *for barley* the temperature must not go above 129.2 degrees nor below 123.8 degrees F.; *for wheat* the temperature must not go above 131 degrees F. nor below 123.8 degrees F.
h. Remove the container to Barrel 4 in order to stop the action of the heat.
i. Dry the grain on a clean surface; do not permit it to sprout or freeze. Shallow layers with frequent shovelling may be necessary. Be careful to prevent reinfection.
j. Sow grain as soon as it is dry enough to run through the drill. The swollen grain is larger than the untreated dry grain, therefore the drill must be set to indicate a proportionately greater sowing.

The hot-water treatment is slow, "messy," and unless special heating facilities are available, it may injure the grain or fail to kill the parasites. We recommend this treatment only for small

seed-plots and not for extensive commercial fields. Although used primarily for loose smuts of barley and wheat, the treatment also controls other seed-borne diseases.

2. *The Formaldehyde Dip.* The formaldehyde dip kills all spores *on the surface* of grain but does not kill parasites *inside* the seed. Like the hot-water treatment it is "messy" and may kill the grain unless it is handled carefully. The treatment is time-consuming. The formaldehyde should be purchased from a reliable druggist and must be full strength (37 per cent solution).

a. The grain should be thoroughly cleaned.
b. Make the disinfectant by adding 1 pint of formaldehyde to 40 gallons of water or ½ pint of the chemical to 20 gallons of water; stir thoroughly.
c. Place not more than ½ bushel of grain in a loosely woven sack, immerse it in the disinfectant, and move the sack about in order to wet all the grain.
d. Drain the disinfectant from the sack back into the barrel or other container, dump the grain on a clean surface, and cover it with damp gunny sacks or canvas for 12-24 hours.
e. Remove the cover and dry the grain until it will run through the drill. In case the grain is not to be planted immediately, it must not be sacked until it is dry.

3. *The Formaldehyde Sprinkle.* For those who prefer the sprinkle method for applying formaldehyde solution, the following directions are given:

a. The grain should be thoroughly cleaned.
b. Make the disinfectant by adding 1 pint of guaranteed 37 per cent formaldehyde to 40-45 gallons of water. This amount of disinfectant will treat approximately 50 bushels of grain.
c. Put the grain in a clean wagon-box or on a clean canvas or floor. Apply the disinfectant with a garden sprinkling can, then thoroughly mix the grain with a rake or shovel. Do not use all the disinfectant at one time, but sprinkle the surface of the grain, then rake or shovel it; apply more disinfectant and stir the grain again.
d. Cover the treated grain with damp sacking for 12 hours; sow as soon as it will run through the drill, or dry and sack it for future sowing.

4. *The Formaldehyde Spray Method.* Since 1917 the spray method for applying formaldehyde has been much used, especial

[61] Haskell, R. J. —The spray method of applying concentrated formaldehyde solution in the control of oat smut. Phytopathology 7: 381-383. 1917.

ly for smuts of oats. Hungerford's modification of the method[102] appears to be less annoying to the operator so far as the fumes are concerned, although just as efficient. Proceed as follows:

a. Use thoroughly cleaned seed.
b. Make a solution of formaldehyde by using 10 parts of water to 1 part of formaldehyde.
c. Place the grain to be treated in a clean wagon box, or on a clean floor or other clean surface.
d. Apply the disinfectant solution with a quart sprayer at the rate of 1 quart to 50 bushels. Two operators are needed: one sprays while the other shovels the grain.
e. Cover the grain with damp sacking or canvas and leave for 5 hours before sowing.

Fig. 56.—How formaldehyde enters and injures seed wheat. Magnified end of a wheat grain showing a very fine crack at "c" which was caused by the threshing machine. Formaldehyde solution easily enters such cracks, but copper carbonate dust does not.

Although the formaldehyde treatments have been used against smuts of various grains such as the oat smuts, bunt of wheat, covered smuts of barley and rye, rice smut, sorghum and millet covered kernel-smut, it should be remembered that some of these

[102] Hungerford, Chas. W.—A modification of the concentrated formaldehyde method of seed treatment—Phytopathology 11: 149-150. 1921.

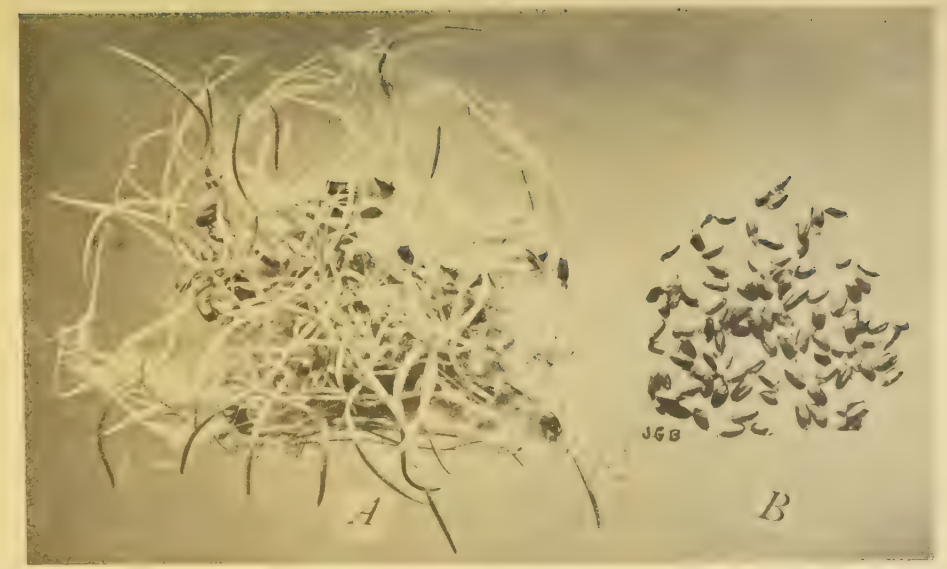

Fig. 57.—Formaldehyde injury of seed wheat. Note weak germination of lot B. Lot A came from the same bin but was not treated.

grains are susceptible to injury from the disinfectant. We recommend the formaldehyde spray only for the smuts of oats for which it is very efficient without extensive injury to the germination.

Wheat is often injured by formaldehyde used on it for smut,[16] perhaps because the grains bear very small cracks (Fig. 56) which result from threshing. In the days of the horse-power and low-speed steam threshers injuries of this kind were absent or infrequent, and comparatively good germination was obtained. With the grain bearing minute cracks the injurious action of the formaldehyde continues during and after drying. The final result may be serious.

On a farm near Pomerene, Arizona, the wheat sowed in a large field failed to germinate properly and there was no stand. The cause was thought to be acid in irrigation water taken from the San Pedro River below a powder factory. Investigation disclosed the fact that the seed had been treated with formaldehyde and then had stood for a day or longer in the sacks before it was sowed. Samples of the wheat, untreated and treated, were obtained whose behavior in the germinator is shown in Figure 57. Even when directions for using formaldehyde disinfectant are followed exactly, as they always should be, there is likely to be a lower percentage of germination in wheat than when dust disinfectants are used. However, oats appear to be resistant to the formaldehyde which is very satisfactory as a disinfectant of the grain for smuts.

Close attention to the directions given for the use of formaldehyde solution on grains is absolutely necessary. Other precautions which should be taken are to treat the grain in the open air, if possible, in order to avoid discomfort from the fumes; also to keep treated grain away from stock until the odor of formaldehyde has entirely disappeared.

5. *The Copper Sulphate Treatment.* The copper sulphate dip was formerly much used for treating seed wheat for bunt or stinking smut. The usual injury to germination can be reduced to a minimum by presoaking the grain and using a lime-water bath after treating, or by washing off the copper carbonate solution following the copper sulphate soak.

Method 1

a. Thoroughly clean the grain. All smut balls should be removed.

b. Soak the grain in water for 10 minutes; keep it damp for 5 hours.

[16] Hurd, Annie May—Injury to seed wheat resulting from drying after disinfection with formaldehyde—Jour. Agr. Res. 20: 209-244. Nov. 1, 1920.

c. Make a solution of copper sulphate (bluestone) by dissolving 2 pounds of the chemical in 20 gallons of water; use a barrel or other *wooden* container for the solution.
d. Put 1 bushel of the grain in a loosely woven sack, immerse in the copper sulphate solution for 5 minutes, meanwhile shaking out the air bubbles.
e. Remove the grain and drain it for 15 minutes.
f. Dip the grain in lime-water consisting of 2 pounds of slaked or hydrated lime stirred in 20 gallons of water.

Method 2

a. Clean grain thoroughly. All smut balls must be removed.
b. Make a solution of copper sulphate (bluestone) by dissolving 1 pound of the chemical in 5 gallons of water in a wooden barrel or trough.
c. Dip the grain in a loosely woven sack in the copper sulphate solution for 3-5 minutes and shake out the air bubbles.
d. Drain off the copper sulphate solution.
e. Dip grain in a lime-water bath made by slaking 2 pounds of quicklime in 16 gallons of water. When the lime-water becomes blue discard it and use a fresh bath.
f. Dry the grain thoroughly before storing.

The strength of the copper sulphate solution can best be maintained by using an hydrometer. A Brix sugar hydrometer well serves the purpose and a glass cylinder will also be needed in which to place the solution to be tested. Directions for testing the disinfectant are as follows: Carefully weigh out the copper sulphate and dissolve the chemical in the quantity of water stated in the method to be followed. Be sure that all the copper sulphate is dissolved. Then dip out enough of the solution to almost fill the glass cylinder, allowing for the space taken up by the hydrometer. Now float the hydrometer in the cylinder and note the reading taken level with the surface of the copper sulphate solution. As the treatment of the grain progresses, take occasional readings by removing some of the used disinfectant and testing it as described. If too weak add more copper sulphate powder or crystals; if too strong, as evidenced by the rising of the hydrometer into the air, add more water.

Dry Seed Treatments

Dry treatments with fungicides in the form of dusts are satisfactory for controlling the covered smuts of wheat, oats, barley, and certain other seed-borne diseases of cereals. Since the loose smuts are of minor importance in Arizona, the much more convenient dry treatments are to be preferred to wet treatments for the small grains.

Advantages of dust treatments are: (a) They can be applied quickly and easily. Two men can treat 3 to 4 tons of seed per

day with the home-made machine described on this page (Fig. 58). (b) The treatments are practically fool-proof. There is little or no danger of losses from impure chemicals, wrong temperatures, improper drying of the grain, sprouting, freezing, or re-contamination of the grain. (c) Grain may be treated and stored at any time, for treated grain retains its vitality. (d) During storage the treated grain is somewhat protected from attack by insects and other animals.

Disadvantages of dust treatments are: (a) The cost of the dust is sometimes higher than wet disinfectants, but the higher cost is partly offset by cheaper application. Some new dusts, however, are quite inexpensive. (b) Treated grain cannot safely be used for food by animals or man. (c) Disinfectant dusts are injurious when inhaled, therefore a respirator or a damp cloth should be worn over mouth and nose by persons who are treating grain. Fumes of formaldehyde are likewise injurious. (d) Fungicidal dusts do not give good smut control when grain treated with them is planted in dry soil. The moisture content of the soil should be favorable for germination. (e) Some dusts, especially copper carbonate, may reduce the rate of seeding or clog the drill unless the latter is cleaned every night and protected from rain.

Unless a treating machine is used for dusting seed, satisfactory results cannot be expected. An inexpensive and serviceable machine can be easily made from a wooden barrel or a steel drum. The accompanying diagram (Fig. 58) illustrating the construction was originally published in North Carolina Agricultural Extension Circular 166. In operation the drum is not more than half filled with seed to which the proper quantity of dust is added. With the door closed the drum is rotated until every kernel is evenly coated with the dust, which will require about fifty turns. Attempts at mixing dust and seed by shovelling, either on a flat surface or in the hopper of the drill, are unsatisfactory. The simplest way to obtain properly treated grain is through arrangement with the management of mills or elevators where the necessary cleaning and dusting machinery is available, thus insuring convenience, thoroughness and economy.

Before it is treated seed grain should be thoroughly cleaned, either at the elevator or with a fanning mill, in order to remove weed seeds, light seeds and other trash, smut balls which may reinfect the seed, and all other debris. Treated grain should be put into new sacks, or into used sacks which have soaked for 1 hour in a solution of 1 quart of formaldehyde in 25 gallons of water, then dried.

A drill containing dusted seed should not stand outside exposed to rain or heavy dew, for the treated grain may then pack and clog the drill. To avoid twisting or breaking the feed shaft, the gear bearings should be kept well oiled; if clogging occurs

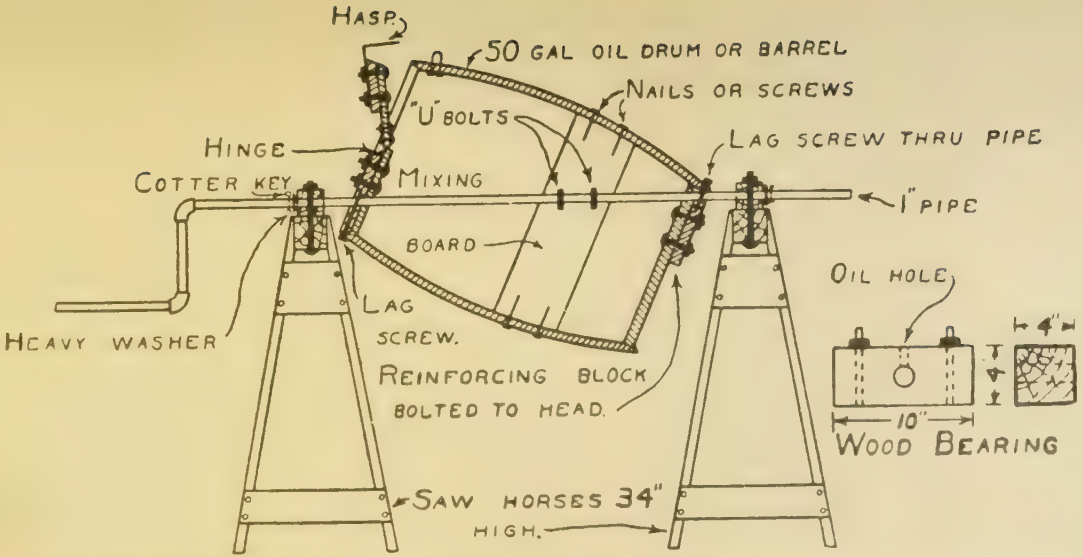

FIG. 58.—Construction plan for a home-made machine for applying disinfectant dusts to seed grain. (From North Carolina Agricultural Extension Circular 166.)

the shaft should be released by rocking the drill wheel or by turning the feed shaft with a wrench before the drill is thrown into gear.

Examples of Dusts Used for Treating Seed

1. *Copper Carbonate.* This is perhaps the most widely used treatment for seed-borne cereal diseases. Copper carbonate which is specially prepared for seed treatment should be used. Full strength copper carbonate containing about 50 per cent metallic copper and a dilute form containing approximately 20 per cent copper are sold for use on seed. There appears to be some difference of opinion as to which is more satisfactory. Two to 2½ ounces of the former and 3 to 4 ounces of the latter per bushel of grain are usually used. Seed treated with copper carbonate does not feed quite so rapidly through the drill as untreated seed, but the small decrease in planted seed is rarely reflected in the yield. However, when the rate of seeding with untreated grain is 6 pecks or less per acre, 1 peck should be added for seed treated with copper carbonate.

2. *Copper Oxide.* Red oxide of copper (cuprous oxide), recently proposed as a seed disinfectant, has given very good results with vegetable seeds. On account of its extraordinary adhesiveness, the chemical is especially valuable for treating smooth seeds. Such seeds will hold two and one-half times as much red oxide as compared with copper sulphate monohydrate. To be effective the red oxide must not have deteriorated to the black cupric oxide which has little fungicidal value. The Department of Plant Pathology is at present testing the value of this compound for the control of cereal smuts.

3. *Copper Sulphate.* Copper sulphate monohydrate dust has given better results than copper carbonate dust in controlling damping-off when it is applied to vegetable seeds. Anhydrous copper sulphate adheres to the seed even better than the monohydrate form. These products may be improvements on the copper carbonate dust, but no data are available on their use with cereals.

4. *Organic Mercury Dusts.* During and since the World War, first in Germany and later in this country, a number of compounds containing organic-mercury salts appeared under various trade names such as "Uspulun," "Germisan" and "Semesan." Many of the earlier compounds were used in liquid form, but there are now commercially available organic mercury dusts like "Ceresan" and "Corona Dust."

Organic mercury dusts are applied by the same method used with copper carbonate dust; the quantity to be used is indicated on the label of the package. "Ceresan" was formerly used at the rate of 3 ounces per bushel of grain, but the new improved

Ceresan is said to give equal results with only ½ ounce of dust per bushel. The new dust is said to be much finer, very adhesive, and the cost per bushel of seed is given as approximately 2 cents. The same treatment is recommended by the manufacturers for covered smut of wheat, covered smut and stripe of barley, and loose and covered smut of oats.

Other organic mercury disinfectants have been developed for special purposes. "New Improved Semesan Jr." and "Merko" are adapted for seed treatment of field and sweet corn. These dusts kill certain seed-borne parasites such as Diplodia, Gibberella, and Basisporium but do not control common smut, for seed-borne spores are unimportant in the spread of this disease. The greatest increases in yield as a result of treatment are found in fields planted with badly infected seed; also the benefits from seed treatment are greater when planting is followed by weather unfavorable to the development of the corn plant. Usually the dusts are applied at the rate of approximately 2 ounces per bushel of dry, shelled, seed corn; the cost of the disinfectant is as low as 3 or 4 cents per acre.

Treated seed should be left in a pile or in sacks for twenty-four hours before it is planted. Organic mercury dusts have been claimed to stimulate the young plants to more vigorous growth, but the effect appears to be temporary and unimportant.

5. *Formaldehyde Dust.* There have been placed on the market several dusts containing formaldehyde as the fungicidal ingredient. The dusts give good control of the oat smuts and are more convenient to use but more expensive than liquid formaldehyde. The treated grain should be held at least five hours or, preferably, over night before sowing.

REFERENCES ON SEED TREATMENT

[104] Holbert, J. R.; Reddy, C. S.; Koehler, Benj.—Chemical dust seed treatments for dent corn -U. S. D. A. Bureau of Plant Industry Circular 34. 1926.

[105] Horsfall, J. G. -Red oxide of copper as a dust fungicide for combatting damping-off by seed treatment N. Y. (Geneva) Agr. Exp. Sta Bul. 615. 1932.

[106] Horsfall, J. G.—Dusting tomato seed with copper sulphate monohydrate for combatting damping-off—N. Y. (Geneva) Agr Exp. Sta Tech. Bul. 198. 1932.

[107] Melhus, I. E.; Reddy, C. S.; Raleigh, W. P. and Burnett, L. C. -Seed treatment for corn diseases- Iowa Agr. Exp Sta Circ 108 1928

[108] Muncie, J. H.—Common diseases of cereals in Michigan- Mich Agr Exp. Sta. Circ. 142. 1932.

[109] Tapke, V. F. and Meier, F. C.—Copper carbonate seed treatment for stinking smut of wheat U. S. D. A. Misc. Circ 108 (revised). 1928

[110] Tisdale, W. H.—Copper carbonate prevents bunt (stinking smut) of wheat—U. S. D. A. Dept. Circ. 394. 1926.

DISINFECTION OF THE SOIL

The prompt disinfection of infected areas of soil is desirable where important soil-dwelling, disease-producing organisms are present. Among the diseases of farm crops to which this statement applies are Texas root rot, crowngall, root knot and others. If the first small infected spot in the field were detected and promptly disinfected much loss would be avoided at low cost and the productive value of the land would be maintained. The kind of disinfectant is important.

A good disinfectant is cheap, efficient, available, and does not leave prolonged harmful effects on the physical and chemical nature of the soil so that subsequent crops are injured. However, when the disease-producing organism is a dangerous one all these qualities save efficiency may be overlooked; the important thing to be accomplished is to kill the organism and thus prevent its spread; harmful effects of the disinfectant on the soil may afterward be repaired. In other cases where a considerable area of more or less isolated land is infected before the dangerous nature of the parasite is realized, the better policy may be to overcome as much as possible the harmful effect of the parasite through the use of fertilizers, wise cultural practices, and especially by planting resistant crops if they are available. Disinfectants should be a first resort in cases of very small infected spots of soil and the last resort in larger infected areas.

To make the best use of disinfecting agents and methods it is necessary to know the life-history of the parasite to be attacked and the condition in which it exists at the time the disinfectant is applied. For instance resistant bodies[111] of the Texas root-rot fungus are sometimes present in the soil; they may not be killed because the disinfectant fails to penetrate them or because the bodies lie so deeply that the agent does not reach them. Fortunately the resting bodies (sclerotia) appear to be absent in the greater part of our root-rot infected land, so far as present investigations go. Another instance is that of root knot caused by the eelworm: larvae and adults are easily killed by disinfectants, but the eggs are very resistant.

DISINFECTION OF THE SOIL

Methods

1. *Drying the soil.* Nature has supplied to farmers of Arizona a disinfecting agent which might be deliberately used much oftener than at present. This disinfectant is dry air combined with prolonged sunshine. Soil infected with various disease-producing fungi, bacteria, and other organisms could be at least partly disinfected, sometimes completely so, by a program of dry working the soil during the months of May, June, October and

[111] King, C. J. and Loomis, H. F.—Further studies of cotton root rot in Arizona with a description of a sclerotium stage of the fungus—Jour. Agr. Res. 39: 641-676. 1929.

November. Frequently only spots in fields need treatment. Soil infested with the Texas root-rot fungus, where the resting bodies of the fungus are absent, may be freed of the disease by dry working and the complete eradication of tap-rooted weeds; the common nematode which causes root knot may also be killed,[112] but the eggs are resistant and the soil must be very dry in order to kill them; Rhizoctonia-infected soil is much improved by dry working.

2. *Flooding.* The flooding of soil for several weeks or even months has been tried in the attempt to destroy harmful organisms. Only where abundant cheap water is available can this method be used; even then the results are probably independable. Flooding for six months killed most of the nematodes in field experiments in California,[113] but some nematodes persisted after the soil had been submerged for one year. Root galls decay faster in wet soil than in dry[113, 114] and the moisture stimulates the hatching of the eggs into worms which are more easily killed. Fungi and bacteria which cause diseases in farm crops are aerobes (organisms which use free oxygen in air), therefore prolonged flooding should kill them. However, the experiments reported by Neal and Wester[115] indicate that the fungus of Texas root rot may remain alive for some time in the absence of oxygen; flooding for one hundred and twenty days failed to eradicate root rot at Iowa Park, Texas.[116] No references are available on the effects of flooding on other soil fungi.

3. *Chemicals.* Since steam sterilization so extensively used by gardeners, truck growers, and greenhouse operators is impractical or unavailable for the farmer, chemicals have come to be used for the disinfection of the soil. For the purpose many chemicals have been tried.[117] Although they are too expensive to be used on large areas, chemical treatments are often practical and even most necessary in checking soil-borne diseases in small spots. The usual procedure is to make a low bank of earth around the infected spot which may be done by throwing a plow-furrow around it and tamping the earth down with a shovel;

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[112] Godfrey, G. H. and Morita, Helene T.—Effects of some environmental factors on the root-knot nematode—Phytopathology 19: 5-6. Jan., 1929.

[113] Tyler, Jocelyn—The root-knot nematode—Cal. Agr. Exp Sta. Circ 330. Dec., 1933.

[114] Jones, Linus H.—The effect of environment on the nematode of the tomato gall—Jour. Agr. Res. 44: 275-285. Feb. 1, 1932.

[115] Neal, D. C. and Wester, R. E.—Effects of anaerobic conditions on the growth of the cotton-root-rot fungus, Phymatotrichum omnivorum Phytopathology 22: 917-920. Nov., 1932.

[116] Taubenhaus, J. J.; Ezekiel, Walter N. and Lusk, J. P. Preliminary studies on the effect of flooding on Phymatotrichum root-rot Amer Jour. Bot. 18: 96-101. 1931.

[117] Newhall, A. G.—Control of root-knot nematode in greenhouses—Ohio Agr. Exp. Sta. Bul. 451. 1930.

with very small spots the dike may be made with a hoe. Into the basin thus formed a solution of formaldehyde (1-2 per cent for fungi and bacteria and at least 5 per cent for nematodes) is run and allowed to penetrate deeply into the soil at the rate of 1 gallon per cubic foot of soil to be disinfected. For the Texas root-rot fungus and similar root-attacking fungi the solution must go down as far as the roots go. Instead of soaking the soil with formaldehyde, the disinfectant may be forced into the soil under pressure by using a specially constructed, pointed soil tube.[118] [119]

The Texas root-rot fungus is sensitive to acid[120] and can be killed with a 2-3 per cent solution of sulphuric acid where sclerotia and medium to large infected roots are absent, according to the junior author. The acid solution is very cheap and improves the soil, since soils in Arizona in which the root-rot fungus grows have an alkaline reaction. Copper sulphate (blue-stone) solution, 1 pound to 20-30 gallons of water, may also be used as a disinfectant on similarly infected soils.

DISINFECTION OF THE SOIL

The chemical treatments mentioned above not only affect the soil-dwelling parasites but also all plants reached by the disinfectant. The stronger chemicals like formaldehyde and carbon disulphide kill crop plants. The discovery by Neal et al[121] that certain compounds of ammonia can be used to kill the root-rot parasite *(Phymatotrichum omnivorum)* without injury to the host is a valuable one. Ammonium sulphate affects the parasite when applied to the soil in quantities four to six times greater than when the chemical is used as a fertilizer. The sulphate may either be broadcast or applied in solution in irrigation water. Infected fields of alfalfa treated with 800-1200 pounds of ammonium sulphate per acre soon show an improved appearance. The heavy treatment of infected spots can often be effected at a low cost. Although the use of ammonium sulphate for Texas root rot in field crops is still in the experimental stage, enough work has been done to demonstrate the possibilities of the treatment.

Experiments with soil disinfectants appear to be increasing. In the field of soil disinfection the greatest need at the present time is a cheaper efficient chemical agent. Advance is being made

[118] King, C. J. and Hope, Claude—Distribution of the cotton root-rot fungus in soil and in plant tissues in relation to control by disinfectants —Jour. Agr. Res. 45: 725-740. 1932.

[119] Harvey, R. B.—Ammonium thiocyanate as a weed eradicant—Jour. Amer. Soc. Agron. 23: 944-946. 1931.

[120] Taubenhaus, J. J.; Ezekiel, Walter N. and Killough, D. T. —Relation of cotton root-rot and Fusarium wilt to the acidity and alkalinity of the soil—Tex. Agr. Exp. Sta. Bul. 389. 1928.

[121] Neal, David C.; Wester, R. E. and Gunn, Kenneth C.—Growth of the cotton root-rot fungus in synthetic media, and the toxic effect of ammonia on the fungus—Jour. Agr. Res. 47: 107-118. 1931.

in this direction and some less costly treatments have been suggested;[132] the rapid progress of plant pathology and agricultural chemistry should soon result in a satisfactory solution of the problem.

[132] Doran, W. L. -Acetic acid and pyroligneous acid in comparison with formaldehyde as soil disinfectants. Jour. Agr. Res. 44: 1932.

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